Effects and Effectiveness of Telemedicine

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The use of telemedicine has recently undergone rapid growth and proliferation. Although the feasibility of many applications has been tested for nearly 30 years, data concerning the costs, effects, and effectiveness of telemedicine are limited. Consequently, the development of a strategy for coverage, payment, and utilization policy has been hindered. Telemedicine continues to expand, and pressure for policy development increases in the context of Federal budget cuts and major changes in health service financing. This article reviews the literature on the effects and medical effectiveness of telemedicine. It concludes with several recommendations for research, followed by a discussion of several specific questions, the answers to which might have a bearing on policy development.

INTRODUCTION

Telemedicine is the use of telecommunications technology to provide health care services to persons who are at some distance from the provider. It involves a spectrum of technologies (Perednia and Allen, 1995; Perednia and Grigsby, 1995) including facsimile, medical data transmission, audio-only format (telephone and radio), still images, and full-motion video. Robotics (Minsky, 1979; Satava, 1992) and virtual reality interfaces (Kelly, 1994) have been introduced into some experimental applications.

To be covered by Medicare, HCFA requires that medical services for processes ordinarily involving physician-patient contact be delivered in person. The use of the telephone for health care delivery is therefore not covered. This policy is presumably intended to contain expenditures and prevent possible over-use. Among telemedicine applications, only those that generally do not involve physician-patient contact are covered by Medicare. HCFA's policy of not paying physicians for services provided using the telephone has complicated the establishment of policy for telemedicine because it is unclear exactly how (and why) the use of the telephone to provide care differs from the use of other telecommunications technologies for the same purpose.

The transmission of radiologic images (teleradiology) is the most commonly used and thoroughly studied application of telemedicine (Andrus and Bird, 1972; Batnitzky et al., 1990; Gitlin, 1986; Ho et al., 1995). With the exception of interventional radiology, radiologists seldom have face-to-face contact with their patients. Because there are no separate procedure codes for teleradiology, it cannot be distinguished from conventional services using billing information. A few diagnostic services, including teleradiology, telepathology, and some telecardiology, are reimbursed by most payers.

The other telemedicine specialty which usually involves no patient contact is telepathology (Bhattacharyya et al., 1995;

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Weinstein, Bloom, and Rozek, 1989). It is, however, much less commonly practiced than teleradiology. In addition, there are four telemedicine procedures that have their own procedure codes. These include electrocardiogram (EKG) transmission, EKG interpretation, and analysis of single or dual chamber pacemaker systems (Physician Payment Review Commission, 1995).

The nature and the limitations of the technology used for telemedicine are fundamental to an understanding of issues surrounding cost and clinical effectiveness. Telemedicine data transmission has employed terrestrial lines (copper telephone wires and optical fibers), terrestrial microwave, radio, and satellites (Chouinard, 1983; Hudson and Parker, 1973; Riggs et al., 1974). The bandwidth or bit rate of the transmission medium (terms used to refer to the amount of information that may be sent per unit of time) is a limiting factor on the type of telemedicine system that may be used. Narrow bandwidth systems, such as ordinary telephone lines (frequently having a bandwidth of 28 or 56 kilobits per second [kbps]), are relatively inexpensive to operate and lack the capacity to transmit full-motion video.

Very broad bandwidth networks, including fiber optic cable and many satellite systems, are capable of carrying sufficient data to permit the use of interactive, full-motion video. So-called T1 lines have a capacity of 1.544 megabits per second (mbps), and T3 lines carry 44.736 mbps. By using data-compression algorithms, interactive television (IATV) may be used with somewhat narrower bandwidths (as narrow as 384 kbps, or approximately one-fourth of the capacity of a T1 line), but the images thus transmitted frequently appear jerky. The use of broad-band networks is more costly because bandwidth is directly related to line charges.

In this article, we are concerned primarily with those telemedicine services not covered, explicitly or implicitly, by Medicare—that is, services that when provided by conventional means ordinarily require the presence of the patient. It is these services that pose the most difficult policy questions for both public and private payers.

The main rationale for the development of telemedicine services has been the desire to provide health services to persons whose access to health care is restricted for one or another reason (Bashshur, 1983; Bashshur and Armstrong, 1976; Puskin, 1995; Sanders and Tedesco, 1993). The National Aeronautics and Space Administration (NASA) and the Department of Defense have thus had a long-standing interest in the development of telemedicine, but others have focused considerable attention on using it with more traditional medically underserved populations, especially residents of rural areas. Various approaches have been developed to meet the health care needs of these individuals, and among them, telemedicine is currently receiving a great deal of attention.

REVIEW OF TELEMEDICINE LITERATURE

Approach

In our recent review of the telemedicine literature performed for HCFA, we were interested first in whether the published research supported the use of telemedicine as a safe, medically effective set of procedures. We attempted to examine the extent to which the literature addressed such issues as costs, cost-effectiveness, effects on patient management, and acceptability of the technology to patients and providers. We chose to limit the scope of this article to issues of costs, effects, and effectiveness, and therefore did not review recent papers addressing various conceptual and policy issues (e.g., confidentiality, licensure, payment, and role of telemedicine within medical information infrastructure). We first used the Medline data base, which yielded approximately 40 percent of the relevant literature. We then checked reference lists in previously identified papers, inquired of colleagues, and conducted searches on the Internet using various "gophers" and newsgroups. This review is not exhaustive, but it covers nearly all the literature.

In reviewing previous studies of telemedicine, it was assumed that the rapid pace of technological advance made even some studies published within the last 5 years out of date. Although the technology of the 1960s and 1970s has long been obsolete, many of the critical policy and social issues addressed during those years remain current (e.g., Bashshur, 1980; Lovett and Bashshur, 1979). We reviewed papers in English, and the foreign literature published in English.

We intended to emphasize well-designed, carefully conducted studies, and assumed that a paper having gone through the peer-review process insures at least some minimal standard of adequacy. We therefore concerned ourselves primarily with papers published in scientific and professional journals. This was somewhat problematic, in that much of the research in telemedicine has been published only in technical reports, or has been presented at conferences, often informally and with little rigor. The literature has many significant gaps. There is little good, systematic research, although there are many reports suggesting the feasibility of a range of applications. The literature is characterized by an array of approaches and technologies, with no replications or cross-validation studies (Grigsby et al., 1993).

Early Telemedicine Projects

Telemedicine has been practiced since at least the 1960s, and many of the issues that today confront providers, researchers, and policymakers previously have been addressed at length (e.g., Bashshur, 1980; Bashshur, Armstrong and Youssef, 1975; Bashshur and Lovett, 1977; Park and Bashshur, 1975). The work of Bashshur and his colleagues from the 1970s is especially valuable in giving the reader an historical perspective on telemedicine. The earliest telemedicine programs were demonstration projects funded by various government agencies. The objective of many of these programs was to establish the feasibility of using interactive telecommunications for diagnosis and treatment of patients at remote sites. Almost none of these programs was self-supporting, and most folded when funding was withdrawn. The one long-standing program in North America is that at the Memorial University of Newfoundland (House and Roberts, 1977; House and Keough, 1992).

Perhaps the first telemedicine program, funded by the National Institute of Mental Health, linked Norfolk State Hospital to the University of Nebraska School of Medicine (Benschoter, 1967; Menolascino and Osborne, 1970; Wittson, Affleck, and Johnson, 1961; Wittson and Benschoter, 1972). In 1967, an interactive network was established between Boston's Logan Airport and Massachusetts General Hospital (Dwyer, 1973), with funding from the U.S. Public Health Service. Through the early 1970s, programs were established in both urban and rural areas, providing consultation for jails, nursing homes (Armstrong, Youssef, and Bashshur, 1975), and other venues.

One of these programs was called Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC).

STARPAHC was funded by NASA, equipped by Lockheed, and implemented on the Papago Indian reservation in Arizona with the cooperation of the Indian Health Service and the Papago people. STARPAHC used telecommunications technology developed to enable NASA to monitor the physiological functioning of astronauts in space (Lovett and Bashshur, 1979; Pool, Stonesifer, and Belasco, 1975), in conjunction with mobile health units. The project demonstrated the feasibility of using advanced technology to bring medical services to remote areas (Bashshur, 1979).

STARPAHC providers gave the project mixed reviews. They appreciated the increased access to certain services, but found the equipment costly, somewhat unreliable, and frequently unnecessary for diagnosis and management of patients (Fuchs, 1979). In their report on the project, Justice and Decker (1979) concluded that there were "no consistent differences in quality of care rendered by the sites equipped with telemedicine systems and staffed by community health medics as compared to the other clinics staffed by physicians within the same health system."

Feasibility of Various Telemedicine Applications

A substantial proportion of the published literature may be classified as addressing the clinical feasibility and effectiveness of telemedicine. That is, the authors discuss a program that was developed, define the target population, and occasionally provide basic descriptive statistics or an impressionistic account of the results (Cunningham, Marshall, and Glazer, 1978; Preston, Brown, and Hartley, 1992; Rayman, 1992; Wittson and Benschoter, 1972). Projects in a wide range of venues and clinical contexts have demonstrated that telemedicine is a feasible endeavor. Although they provide interesting information regarding the possible range of applications, papers of this sort are of limited utility for the evaluation of telemedicine. In this section, we will primarily discuss different telemedicine projects that have demonstrated their feasibility.

In addition to those early telemedicine programs previously discussed, the feasibility of telemedicine has been demonstrated by other projects in the civilian sector. This has been the case for a number of specialties and subspecialties, including anesthesiology (Gravenstein, et al., 1975), cardiology (Bird, 1972; Finley et al., 1989), critical care medicine (Grundy, Jones, and Lovitt, 1982), dermatology (Murphy et al., 1972; Perednia and Brown, 1995); neonatology (Jones, Jones, and Halliday, 1980); neurology (Chaves-Carballo, 1992; Hubble, 1992); oncology (Allen, Cox, and Thomas, 1992); otorhinolaryngology (Pedersen, Hartviksen, and Haga, 1994; Rinde, Nordrum, and Nymo, 1993), pediatrics (Cunningham, Marshall, and Glazer, 1978), and psychiatry (Brown, 1995; Dwyer, 1973; Preston, Brown, and Hartley, 1992; Solow et al., 1971; Straker, Mostyn, and Marshall, 1976).

Telemedicine projects have tested the feasibility of using the spectrum of technologies, from fax, radio, and telephone through the transmission of still images and real-time interactive television (Bertera and Bertera, 1981; Bertrand et al., 1994; House and Keough, 1992; House et al., 1987; Padeken et al., 1995; Rinde, Nordrum, and Nymo, 1993; Sanders, 1976; Sanders and Samsor, 1973; Smego et al., 1993; Turner, Brick, and Brick, 1995; Wasson et al., 1992). Telemedicine has been attempted in as broad a range of environments as might be imagined (Lovett and Bashshur, 1979), including space (Pool, Stonesifer, and Belasco, 1975), desert warfare (Cawthon et al., 1991), and the Antarctic (Siderfin, 1995) as well as the more mundane settings of hospital, clinic, long-term care facility, and home (Finkelstein et al., 1993; Sparks et al., 1993).

NASA has long used telemedicine for its astronauts (Pool, Stonesifer, and Belasco, 1975), and more recently the agency has established telemedicine links with former Soviet republics for disaster relief (Houtchens et al., 1993; Nicogossian, 1989). Specifically, the Spacebridge to Armenia/Ufa project provided assistance to persons involved in the 1989 earthquake in Armenia and a major gas explosion in Ufa. Spacebridge to Moscow was used to provide consultations regarding persons injured in the civil insurrection of October 1993. Ferguson, Doarn, and Scott (1995) briefly surveyed NASA's activities, and discussed other (non-NASA) telemedicine applications throughout the world.

The armed services have had an interest and involvement in both mobile health and telemedicine services for some time. Advanced telecommunications technology was used in conjunction with mobile health units during the war in the Persian Gulf (Cawthon et al., 1991), demonstrating that these two technologies can be integrated, even under difficult geographic and climatologic circumstances, with beneficial effect (Spiller, Hellstein, and Basquill, 1990). Computerized tomography (CT) scanners were installed in transportable modular military hospital units and deployed in the Saudi desert just south of the Iraqi and Kuwaiti borders. Cawthon et al. (1991) indicated that both the operation of the mobile units and the satellite-transmitted CT images were of good quality, although a methodologically rigorous study was not conducted.

The armed forces are engaged in a large-scale program of telemedicine research and development. This includes the distant physiological monitoring of deployed troops, and investigation of such technologies as telepresence (Green, Hill, and Satava, 1991), virtual reality, and telerobotic laparoscopic surgery (Satava, 1992, 1993). The Army has experimented with telemedicine to provide care to persons living on remote islands in the Pacific Ocean (Delaplain et al., 1993). The Army also has deployed telemedicine units to Somalia, Haiti, Macedonia, and Croatia (Crowther and Poropatich, 1995; Laughlin and Legters, 1993), using consultants at Walter Reed Army Medical Center and the Army medical center in Landstuhl, Germany.

Effectiveness of Various Telemedicine Applications

Because the effectiveness of the medical care provided by telemedicine has been evaluated only superficially, we are unable, from the published literature, to assess the utility of telemedicine vis à vis conventional care. Low patient volumes (Allen, 1993; Grigsby, 1995a) and the small number of active telemedicine programs have made it impossible to conduct large-scale, cross-cutting evaluations of the effectiveness of telemedicine (Perednia, 1995). Moreover, several factors have served as impediments to the full deployment of telemedicine systems, keeping patient volumes down (Grigsby et al., 1994b; Puskin, 1995; Sanders, 1993). Puskin and Sanders (1995) categorized these as problems of: (1) technology or telecommunications infrastructure; (2) human or organizational infrastructure; and (3) health care financing infrastructure.

Neurology

Small, narrow studies of effectiveness have been conducted within several specialties and within general internal medicine. For example, interactive video was successfully used for the examination and rating of patients with Parkinson's disease (Hubble, 1992; Hubble et al., 1993), using the Hoehn and Yahr (1967) score and the Unified Parkinson's Disease Rating Scale (Lang and Fahn, 1989).

Cardiology

Murphy and colleagues (1973) studied the effectiveness of cardiac auscultation via microwave transmission. Using an electronic stethoscope, they examined 50 persons, 27 of whom were patients whose diagnoses were already known. All systolic murmurs heard by direct auscultation were also detected by the telediagnostic system. There were neither false positives nor false negatives. There was a slight difference in the grading of murmurs by the two methods in 5 of 24 cases, but no consistent direction to the discrepancy. The findings were somewhat more mixed with respect to diastolic murmurs. There was 100 percent agreement on diastolic murmurs heard at the left sternal border, but only 75 percent (6 of 8) on those at the apex, in favor of direct auscultation. The 2 missed murmurs were described as "faint (Gr 1/6), rumbling murmurs." In 3 cases there were differences in grading.

In a small study (n = 7) using an electronic stethoscope for remote auscultation with pediatric patients, Mattioli and colleagues (1992) reported generally good sensitivity and specificity when the data were compared with the results of conventional auscultation. The authors noted that the remote equipment demonstrated 100 percent sensitivity for the presence of cardiac disease and for the need for a follow-up exam. The results of these studies of auscultation were suggestive, but replication of the research with larger samples would be valuable.

Sobczyk and colleagues (1993) studied the accuracy of telediagnosis for pediatric echocardiography. The authors used a relatively "low tech" system, transmitting data via modem over standard telephone lines. In a series of 47 patients (24 normals), 83 percent "were thought to give accurate diagnostic impressions compared with videotape review." Of the incorrect impressions (17 percent of the total), only one was considered to be a function of problems with the information transmitted. In the others, the authors argued that most of the errors resulted from "the selection and transmission of an image without sufficient information to allow a definite diagnosis." They did not explain how they reached this conclusion.

Transmission of EKGs has been studied by at least two groups (Bertrand et al., 1994; Ong et al., 1995). Bertrand and colleagues (1994), using an off-the-shelf fax machine and standard phone lines, found that, of a total of 1,568 transmissions, cardiologists rated the quality of the faxed EKGs as either "good" (95.8 percent) or "excellent" (4.2 percent) in all cases. Ong and colleagues (1995) used a flatbed scanner to digitize EKGs, then transmitted them by modem. They were then displayed on the consultant's monitor and printed on a laser printer using standard EKG paper. According to the authors, all 200 EKGs transmitted were graded as "excellent." A resolution of 600 dots per inch provided greater resolution, but the cardiologists "were satisfied" with a resolution of 300 dots per inch.

Dermatology

The first study of dermatologic diagnosis via television was done by Murphy and colleagues (1972), using a set of 75 color slides projected onto a screen to produce an image measuring 3 feet by 2-1/2 feet. The image was then photographed by a television camera and displayed on both black-and-white and color television monitors. Physicians made diagnoses from either direct viewing of the slides or from the televised images. In comparison with a "gold standard" of known diagnoses, diagnostic accuracy was slightly lower for the televised images than for the slides, perhaps in large part because of the equipment used. Color images yielded slightly greater accuracy than did black and white. Although Perednia and Brown (1995) described research in progress, there have been no other studies of the effectiveness of telemedicine applied to dermatology.

Psychiatry

The effectiveness of psychiatry is notoriously difficult to demonstrate. Nevertheless, there have been attempts to evaluate the use of telepsychiatry. Dongier and colleagues (1986) reported preliminary data from a study of 50 patients selected for telemedicine and 35 controls (face-to-face interviewing). Patients showed no significant differences in level of satisfaction with the two approaches, although both consultants and primary care providers rated the IATV interviews as inferior to in-person interviews.

It appears that the only other attempt at a controlled study of telepsychiatry was conducted by Ball and colleagues (1995) who examined four modes of interaction—face-to-face, telephone, hands-free telephone, and a desktop computer-based video conference system. The design was not entirely clear from the report, and the sample size was small (six patients and six physicians) and heavily weighted toward severe psychopathology (three schizophrenics and one paranoid disorder among the six). The video system "induced the greatest frustration, the least sense of having been understood, and the most disappointment with the consultation" among the patients. Physicians reported no differences in satisfaction among the four modes, but preferred the presence of visual information. The findings of this study are inconclusive.

Otorhinolaryngology

Pedersen, Hartviksen, and Haga (1994) reported on a preliminary study of telemedicine for otorhinolaryngology. The data provided demonstrated that an ear, nose, and throat (ENT) physician was able to make diagnoses using the telemedicine system. In one condition, after having examined the patient by IATV from another room, the specialist went into the exam room with the patient and conducted a face-to-face examination. There was complete concordance for the specialist's diagnoses on all 17 patients, a finding that might have carried more weight had a second specialist done the face-to-face exams.

Fetal Ultrasound

Preliminary data indicating that physicians found transmitted fetal ultrasound indistinguishable from standard ultrasound, "with almost no perceptible loss of picture quality or frame rate at the receiving end," were reported by Fisk and colleagues (1995).

Trauma and Disaster Medicine

Houtchens and colleagues (1993) discussed NASA's use of telemedicine for disaster response in the former Soviet Union. In the Armenian quake, the emphasis was on tertiary care from various specialties and diagnostic imaging. The gas explosion in Ufa required consultation regarding burn care. Consults were obtained on a total of 209 patients, with significant effects on patient management. Fifty-four diagnoses were changed, the interpretation of 27 diagnostic studies was altered, and the diagnostic process and treatment plans were both changed in 47 cases. Among surgical cases, nearly one-half of the diagnoses were changed. The system was used for public health conferences in Armenia, and for psychiatric conferences regarding posttraumatic stress disorder. Although extensive data were not collected in these relief efforts, the effects of telemedicine on patient management were well documented. Disaster response has also been discussed by Llewellyn (1995).

Home Health Care

There has been much discussion of telemedicine as an adjunct to home health care, but very little work has been done in this area. Some studies, however, demonstrate the effectiveness of monitoring patients following lung and heart-lung transplants (Finkelstein et al., 1993), and monitoring the exercise programs of cardiac rehabilitation patients (Sparks et al., 1993). In the first of these studies, the authors used an electronic diary-spirometry instrument to record spirometry and data on vital signs and symptoms on a daily basis. Data were stored in the instrument and periodically transmitted to the clinic. The measures appeared to be both valid and reliable, and the compliance rate was approximately 90 percent, suggesting that this is a viable method of monitoring pulmonary function in these patients.

Sparks and colleagues (1993) studied 20 cardiac patients randomly assigned to either a hospital rehabilitation program or home-based, telephonically monitored exercise. After 12 weeks of training, there were no differences between groups (although the small sample seriously limits the statistical power), both of which demonstrated improvements in cardiovascular functioning. The monitoring permitted the detection of new arrhythmias in two of the home-based patients, and their management was altered.

Telemedicine in General

Few studies have compared the effectiveness of different levels of technology in telemedicine consultation. Murphy and Bird (1974) reported on their study of 1,000 patients seen at the Logan Airport Medical Station, which was attended by nurses for all but the 4 hours of each day coincident with peak passenger flow, when a physician was present. These patients thus comprised a group of patients for whom the nurse sought medical consultation from a physician at a remote site. The first 200 patients were examined both via telemedicine and by a physician at the medical station. The article does not make clear whether diagnoses were reached independently, but it noted that in 96 percent of cases the in-person physician "concluded that his own disposition would not be significantly different." According to the authors, among the remaining 800 patients, telemedicine could not determine the diagnosis for only 2 percent.

Moore and colleagues (1975) examined the relative effectiveness of telephone versus televised consultation with physicians by nurse practitioners in three nurse-run clinics. During the 7-month study period, 1,408 patients visited the clinic, and of these a total of 354 required consultation between nurse and a remote physician. Telemedicine consultation visits were about 25 percent longer than telephone visits, and the amount of time actually spent on-line with the consultant was nearly twice as long for telemedicine. Telephone consults were twice as likely to result in a patient traveling immediately to the hospital for a visit. With television, when follow-up was required it could more frequently be done in a neighborhood outpatient clinic.

Patients were generally satisfied with both modes of delivery, and providers tended to prefer whichever mode they had just used.

A third study compared conventional medical care with 4 modes of telemedicine—color television, black-and-white television, still black-and-white images, and hands-free telephone (Conrath et al., 1977). From a rural telemedicine program in Ontario, a total of 1,015 patients were randomly assigned to one each of these four groups while waiting to be examined face-to-face by another physician. Every patient thus had two successive physician appointments, one by telemedicine and one in person. Following the first (telemedicine) exam, the physician gave no information to the patient regarding diagnosis or recommended treatment. This was left up to the second (in-person) physician.

Diagnostic concordance was 61 percent, which compared favorably with what the researchers had previously found for two attending physicians in face-to-face contact with the patient. There were no differences between the groups assigned to different levels of technology with respect to the accuracy of diagnosis. This held true for 17 of 18 different disease categories. The exception was dermatology, where the ability to see skin lesions is very important. Although physicians expressed greater confidence in diagnoses made using the IATV systems, the differences were not significant. In-person physicians ordered fewer tests than the telemedicine physicians, who did not differ among themselves. There were no significant differences in patient management across the four modes, or in comparison with face-to-face consultation. There were no striking differences in patient satisfaction across the different modes, although there was evidence for a slight preference for color IATV.

Summary of Effectiveness

The effectiveness of only a few telemedicine applications has been established empirically. The research conducted to date has dealt largely with very focused questions (e.g., the accuracy of auscultation), and has been characterized by small samples and methodologic weaknesses. It appears that many telemedicine applications may be effective means of providing health services (Grigsby et al., 1994a), and telemedicine may certainly affect patient management (e.g., Houtchens et al., 1993), but it is difficult at present to assess telemedicine in relation to conventional medical care. Although one should not expect telemedicine to be validated more thoroughly than has been the case for ordinary health services, and it should not be necessary to evaluate all of telemedicine (Grigsby et al., 1995), it is important to understand how the two modes of delivery compare.

The studies by Moore and colleagues (1975) and Conrath and colleagues (1977) suggest that expensive IATV systems are not necessary for a broad range of telemedicine applications. It seems a reasonable hypothesis that most health care provided via telemedicine could be accomplished using "store and forward" technology, in which data captured at the time of a consult are transmitted to a specialist for later review using a desktop computer telemedicine system. Primary-care providers could obtain consultation from specialists by electronically transmitting written or audio information in conjunction with still visual images or short video clips. Real-time IATV may be necessary only for a limited number of applications (e.g., psychiatric exams). The issue is complex because it is confounded by HCFA's policy of not covering services delivered by telephone. Thus the choice of technology may be driven more by existing policy than by actual clinical needs (Perednia and Grigsby, 1995).

Cost-Effectiveness of Telemedicine

Although in some papers the costs of a specific system were discussed, there were no studies in the medical literature that addressed the issue of cost-effectiveness. Demonstration of the cost-effectiveness (or lack thereof) of telemedicine thus remains several years in the future. In the meantime, certain variables contributing to costs and revenues (e.g., line charges, equipment costs, possible reimbursement, low patient volumes) can be expected to be volatile and unpredictable. One should also keep in mind that telemedicine is not a monolithic entity, but consists of a spectrum of technologies and applications. Specific telemedicine applications may or may not be found to be cost-effective. Studies of telemedicine en bloc are unlikely to shed light on the issue. At this time, statements about the cost-effectiveness of telemedicine should probably be regarded as largely conjecture.

Acceptability to Providers and Patients

Few careful studies of patient and provider satisfaction have been published. Higgins, Conrath, and Dunn (1984) attempted a study of provider acceptance of telemedicine in the Sioux Lookout program in Ontario. The study was limited by a small sample, and a detailed description of the methodology was not provided. In general, the 34 nurses were more positive about telemedicine than were the four physicians. Two physicians described themselves as "positive" about the system, while two were "neutral." The authors' strongest conclusion may have been that "provider acceptance of telemedicine is extremely difficult to measure."

More recently, Allen et al. (1995) reported on a study of physician (medical oncologist) satisfaction with IATV for an initial patient visit. Three oncologists completed a nine-item questionnaire that inquired about their contacts with each of 34 patients over a period of 4 days. They also completed a second, four-item questionnaire at the end of each teleoncology clinic day. A variant of the nine-item questionnaire was completed after each patient visit on a day when seven patients were seen face-to-face in clinic. As the authors noted, the sample size was too small to make this research anything more than a preliminary study, and there was no variability in the responses to the in-person survey (all respondents gave the maximum possible score). Nevertheless, ratings of telemedicine were generally favorable. Specific responses appeared to reflect frustration with the equipment, concerns about whether all relevant information was being transmitted, and difficulty in asking intimate questions of the patients.

Bashshur (1978) was the first to study patient acceptance of telemedicine. In a well-designed study, he studied both community attitudes toward telemedicine, and the effects of experience with telemedicine on those attitudes. The findings of the community survey showed that among persons not yet exposed to telemedicine, large majorities believed that the use of telemedicine would be less satisfactory than seeing a physician in person. In the second part of the study, a sample of 72 patients was asked to complete attitude survey instruments before and after their first telemedicine contact. The sample was almost evenly divided among those who thought telemedicine would be the same as an in-person visit, those who thought it would create problems, and those who said they didn't know. Following the telemedicine session, 67 percent thought it had been about the same as in-person care and only 17 percent thought it was less satisfactory than a face-to-face visit. The remainder were unsure, and no one thought telemedicine was superior. As Bashshur noted, "familiarity did breed comfort."

A more recent pilot study of patient satisfaction with teleoncology was reported by Allen and Hayes (1995). They administered a short survey to 39 cancer patients following a first telemedicine session, and followed up with a similar survey of 21 of these patients following a subsequent in-person visit with the same physician who had conducted the telemedicine consult. Patients were generally satisfied with telemedicine, although after the in-person visit they were less inclined to use the IATV system again. Patients also found it more difficult to be candid over the video system. The reluctance to use the system again contrasts with the findings of Pedersen and Holland (1995) who surveyed 24 ENT patients after undergoing tele-endoscopy. Only one patient expressed dissatisfaction, whereas 18 were "very satisfied" with the exam. Twenty-one of the 24 expressed a preference for tele-endoscopy on another occasion rather than having a specialist travel 250 kilometers from a tertiary care facility (or traveling that distance themselves).

It seems apparent that certain telemedicine applications may be an acceptable means of providing medical care for a large percent of persons. There are no application-specific data, however, and the reasons for dissatisfaction or satisfaction are unknown. In Bashshur's (1978) study, familiarity with telemedicine changed attitudes in a positive direction, but in the work by Allen and Hayes (1995), patients nonetheless would prefer not to have a second telemedicine contact. It seems that a number of demographic, clinical, process, and personality variables may affect patient acceptance of telemedicine.

The studies of provider acceptance of telemedicine suggest that non-physician providers are more accepting of telemedicine than are physicians. Reasons for provider discomfort with telemedicine were discussed by Grigsby et al. (1994b). If physicians are going to use telemedicine, certain basic issues need to be addressed in the organization and functioning of telemedicine systems, and more research must be done on the effects and effectiveness of the technology.

TELEMEDICINE RESEARCH NEEDS

Overview

We know very little about the costs, effects, and effectiveness of telemedicine. Nonetheless, all indications are that the private sector is aggressively engaged in the proliferation of telemedicine, despite the fact that Congressional budget blueprints call for reductions in appropriations for telemedicine research and development. The technology used in telemedicine is relatively complex and constantly changing. Given the rate of development of new technologies and applications, the state of the art in telemedicine can be expected to change rapidly. Robotics already plays a role in the use of microscopes by pathologists, and further developments will surely be introduced. The Department of Defense is investigating telerobotic laparoscopic surgery, with surgery performed remotely on patients by surgeons who manipulate instruments from a distant site. Likewise, virtual reality technology is rapidly gaining entry into medicine. These technologies will require extensive evaluation.

The extent to which Medicare should be involved in the evaluation of telemedicine is unclear. Medicare has an interest in the effects of widespread proliferation and integration of telemedicine technologies into the health care system. Given that Medicare beneficiaries are largely older persons with a greater burden of health care needs, costs to Medicare could be significantly higher than to other payers. There is currently a dearth of information on the effects of telemedicine on such matters as costs, access, practice patterns, and patient management, and policy development could be enhanced by the acquisition of data on these subjects. Other research topics that would help inform Medicare policymakers include the areas of payment, use, appropriateness, and outcome-based quality assurance.

Specific Research Questions

There are several pressing health services issues in telemedicine that require thorough study (Bashshur, 1980, 1995; Grigsby et al., 1994c). These include the following questions.

- Are specific telemedicine applications medically effective means of delivering health care? There is a need for studies of efficacy and effectiveness. No one wants to provide, receive, or pay for care that is ineffective. Beyond this, if health care organizations and providers are to offer good quality services, it is essential to establish the relationship between level of technology and short-, intermediate-, and long-term health outcomes. For example, if store-and-forward technology is medically effective for a wide range of applications (e.g., management of chronic conditions, surgical follow-up, routine consultation), the use of full-motion video may be unnecessary in those cases. At the same time, it is important to determine which applications require interactive television (e.g., psychiatry). These questions should be answered for each specific category of telemedicine applications (e.g., management of acute and self-limited conditions, medical and surgical follow-up, management of chronic disorders, extended diagnostic work-ups, triage and emergency consultation, and routine consultation or second opinions). Finally, the need to assess the safety and effectiveness of emerging technologies in telemedicine (e.g., robotics, virtual reality) is obvious.
- What are the costs involved in specific telemedicine applications, and are these applications cost-effective means of providing health care? In the past, the introduction of new technologies has often been accompanied by claims of efficacy and cost-effectiveness. Most technological advances, however, have increased the costs of medical care. The Medicare End Stage Renal Disease (ESRD) program was a clear illustration of the unanticipated expenses that might ensue from widespread expansion of coverage for certain interventions (Iglehart, 1993; Levinsky, 1993). Experience with the ESRD program demonstrates the need for a systematic program of research surrounding the introduction of new health care technologies.

  Given the rapidity of technological change and the striking decreases in the cost of equipment, it is quite likely that the cost-effectiveness of telemedicine systems will change significantly over the next several years. Moreover, until the rapid growth and proliferation of telemedicine have stabilized, it may be difficult to assess cost-effectiveness accurately.
- What processes of telemedicine care are associated with optimal health outcomes? At present there are no clear standards of practice in telemedicine, yet it seems likely that not all approaches to using the technology will be equally effective. It has yet to be determined which kinds of

providers (e.g., physicians, physician assistants, nurse practitioners) are most effective and least costly, and what their respective roles ought to be.

- Can appropriate use be defined? Both public and private payers are concerned with the possibility of over-use of services and its effect on expenditures. A high rate of use of a given service throughout the system may also expose patients to increased levels of risk associated with unnecessary procedures (e.g., risk of complications, adverse effects, iatrogenic and nosocomial disorders, anxiety, discomfort) without any increased benefit (Palmer, 1991). On the other hand, under-use may be problematic in that necessary or beneficial care may be unavailable to patients. Payment mechanisms that limit access to appropriate services lead to under-use and poor quality (Schroeder, 1991).

  Research is needed to establish appropriate use levels of various telemedicine services for different clinical situations. Data of this sort could facilitate the development of empirically derived use guidelines that might focus on specific classes of clinical problems (e.g., emergency consultation).

- How should payment for telemedicine services be handled? There are many problems that must be resolved in establishing a payment policy (Grigsby, 1995b). These include coding, provider characteristics, number of providers to be paid, relative value units, geographic variation, payment methods for different applications, and payment rates. For example, in many programs, both primary-care and consulting physicians participate in each consult, an arrangement that is unlikely to be cost-effective. The results of research on effectiveness and cost-effectiveness can be used to inform payment policy.

CONCLUSION

In a context of tightened budgets, increasing costs, and fundamental changes in the organizational infrastructure of health care, telemedicine is emerging rapidly. Serious consideration of the technology suggests that it has the potential to affect health services delivery in many ways, but rapid technological change and a volatile and changing health care system make it extremely difficult to predict the directions that will be taken. Past experience shows that unanticipated consequences are likely, and that these may have significant effects on the health care system.

Considerable study will be necessary before we have a good understanding of the effects and effectiveness of telemedicine. Careful research conducted now may go a long way toward the establishment of a rational policy toward telemedicine.

REFERENCES

Allen, A.: Patient-Physician Consultations via Interactive Video in 1993. *The Telemedicine Newsletter* 1(4):1-3, 1993

Allen, A., Cox, R., and Thomas, C.: Telemedicine in Kansas. *Kansas Medicine* 93:323-325, 1992.

Allen, A., and Hayes, J.: Patient Satisfaction With Teleoncology: A Pilot Study. *Telemedicine Journal* 1:41-46, 1995.

Allen A., Hayes J., Sadasivan R., et al.: A Pilot Study of the Physician Acceptance of Tele-Oncology. *Journal of Telemedicine and Telecare* 1:34-37, 1995.

Andrus, W.S., and Bird, K.T.: Teleradiology: Evolution Through Bias to Reality. *Chest* 62:655-657, 1972.

Armstrong, P.A., Youssef, Z.I., and Bashshur, R.L.: Telemedicine in the United States: A Summary of Operational Programs. In Bashshur, R.L., Armstrong, P.A., and Youssef, Z.I., eds.: *Telemedicine: Explorations in the Use of Telecommunications in Health Care.* Springfield, IL. Charles C. Thomas, 1975.

Ball, C.J., McLaren, P.M., Summerfield, A.B., et al.: A Comparison of Communication Modes in Adult Psychiatry. *Journal of Telemedicine and Telecare* 1:22-26, 1995.

Bashshur, R.: Public Acceptance of Telemedicine in a Rural Community. *Biosciences Communications* 4:17-38, 1978.

Bashshur, R.: *Technology Serves the People: The Story of a Co-Operative Telemedicine Project by NASA, The Indian Health Service, and the Papago People.* Tucson, AZ. The Indian Health Service, 1979.

Bashshur, R.: A Proposed Model for Evaluating Telemedicine. In Parker, L. and Olgren, C., eds.: *Teleconferencing and Interactive Medicine.* Madison, WI. University of Wisconsin, 1980.

Bashshur, R.: Telemedicine and Health Policy. In Gandy, O.H., Espinosa, P. and Ovdover, J.A., eds.: *Proceedings From the Tenth Annual Telecommunications Policy Research Conference.* Ablex Publishing, 1983.

Bashshur, R.L.: On the Definition and Evaluation of Telemedicine. *Telemedicine Journal* 1:19-30, 1995.

Bashshur, R.L., and Armstrong, P.A.: Telemedicine: A New Mode for the Delivery of Health Care. *Inquiry* 13:233-244, 1976.

Bashshur, R.L., Armstrong, P.A., and Youssef, Z.I.: *Telemedicine: Explorations in the Use of Telecommunications in Health Care.* Springfield, IL. Charles C. Thomas, 1975.

Bashshur, R., and Lovett, J.: Assessment of Telemedicine: Results of the Initial Experience. *Aviation, Space, and Environmental Medicine* 48:65-70, 1977.

Batnitzky, S., Rosenthal, S.J., Siegel, E.L., et al.: Teleradiology: An Assessment. *Radiology* 177:11-17, 1990.

Benschoter, R.: Multipurpose Television. *Annals of the New York Academy of Sciences* 142:471-478, 1967.

Bertera, E.M., and Bertera, R.L.: The Cost-Effectiveness of Telephone Vs. Clinic Counseling for Hypertensive Patients: A Pilot Study. *American Journal of Public Health* 71:626-629, 1981.

Bertrand, C.A., Benda, R.L., Mercando, A.D., et al.: Effectiveness of the Fax Electrocardiogram. *American Journal of Cardiology* 74:294-295, 1994.

Bhattacharyya, K., Davis, J.R., Halliday, B.E., et al.: Case Triage Model for the Practice of Telepathology. *Telemedicine Journal* 1:9-17, 1995.

Bird, K.T.: Cardiopulmonary Frontiers: Quality Health Care via Interactive Television. *Chest* 61:204-205, 1972.

Brown, F.W.: A Survey of Telepsychiatry in the USA. *Journal of Telemedicine and Telecare* 1:19-21, 1995.

Cawthon, M.A., Goeringer, F., Telepak, R.J., et al.: Preliminary Assessment of Computed Tomography and Satellite Teleradiology From Operation Desert Storm. *Investigative Radiology* 26:854-857, 1991.

Chaves-Carballo, E.: Diagnosis of Childhood Migraine by Compressed Interactive Video. *Kansas Medicine* 93:353, 1992.

Chouinard, J.: Satellite Contributions to Telemedicine: Canadian CME Experiences. *Canadian Medical Association Journal* 128:850-855, 1983.

Conrath, D.W., Dunn, E.V., Bloor, W.G., and Tranquada, B.: A Clinical Evaluation of Four Alternative Telemedicine Systems. *Behavioral Science* 22:12-21, 1977.

Crowther, J.B., and Poropatich, R.: Telemedicine in the U.S. Army: Case Reports From Somalia and Croatia. *Telemedicine Journal* 1:73-80, 1995.

Cunningham, N., Marshall, C., and Glazer, E.: Telemedicine in Pediatric Primary Care: Favorable Experience in Nurse-Staffed Inner-City Clinic. *Journal of the American Medical Association* 240:2749-2751, 1978.

Delaplain, C.B., Lindborg, C.E., Norton, S.A., and Hastings, J.E.: Tripler Pioneers Telemedicine Across the Pacific. *Hawaii Medical Journal* 52:338-339, 1993.

Dongier, M., Tempier, R., Lalinec-Michaud, M., and Meunier, D.: Telepsychiatry: Psychiatric Consultation Through Two-Way Television. A Controlled Study. *Canadian Journal of Psychiatry* 31:32-34, 1986.

Dwyer, T.F.: Telepsychiatry: Psychiatric Consultation by Interactive Television. *American Journal of Psychiatry* 130:865-869, 1973.

Ferguson, E.W., Doarn, C.R., and Scott, J.C.: Survey of Global Telemedicine. *Journal of Medical Systems* 19:35-46, 1995.

Finkelstein, S.M., Lindgren, B., Prasad, B., et al.: Reliability and Validity of Spirometry Measurements in a Paperless Home Monitoring Diary Program for Lung Transplantation. *Heart and Lung* 22:523-533, 1993.

Finley, J.P., Human, D.G., Nanton, M.A., et al.: Echocardiography by Telephone—Evaluation of Pediatric Heart Disease at a Distance. *American Journal of Cardiology* 63:1475-1477, 1989.

Fisk, N.M., Bower, S., Sepulveda, W., et al.: Fetal Telemedicine: Interactive Transfer of Realtime Ultrasound and Video via ISDN for Remote Consultation. *Journal of Telemedicine and Telecare* 1:38-44, 1995.

Fuchs, M.: Provider Attitudes Toward STARPAHC, a Telemedicine Project on the Papago Reservation. *Medical Care* 17:59-68, 1979.

Gitlin, J.N.: Teleradiology. Radiological Clinics of North America 24:55-68, 1986.

Gravenstein, J.S., Berzina-Moettus, L., Regan, A., and Pao, Y-H.: Laser Mediated Telemedicine in Anesthesia. *Anesthesia and Analgesia* 53:605-609, 1975.

Green, P.S., Hill, J.H., and Satava, R.M.: Telepresence: Dextrous Procedures in a Virtual Operating Field. *Surgical Endoscopy* 57:192, 1991.

Grigsby, J.: Current Status of Domestic Telemedicine. *Journal of Medical Systems* 19:19-27, 1995a.

Grigsby, J.: *Telemedicine Policy: Coverage and Payment.* Denver. Center for Health Policy Research, 1995b.

Grigsby, J., Kaehny, M.M., Schlenker, R.E., et al.: Telemedicine: *Literature Review and Analytic Framework.* Denver. Center for Health Policy Research, 1993.

Grigsby, J., Barton, P.L., Kaehny, M.M., et al.: *Telemedicine Policy: Reimbursement, Quality Assurance, and Utilization Review.* Denver. Center for Health Policy Research, 1994a.

Grigsby, J., Sandberg, E.J., Kaehny, M.M., et al.: *Telemedicine case studies and current status of telemedicine.* Denver. Center for Health Policy Research, 1994b.

Grigsby, J., Schlenker, R.E., Kaehny, M.M., et al.: *Telemedicine study summary and recommendations for further research.* Denver. Center for Health Policy Research, 1994c.

Grigsby, J., Schlenker, R.E., Kaehny, M.M., et al.: Analytic Framework for Evaluation of Telemedicine. *Telemedicine Journal* 1:31-39, 1995.

Grundy, B.L., Jones, P.K., and Lovitt, A.: Telemedicine in Critical Care: Problems in Design, Implementation, and Assessment. *Critical Care Medicine* 10:471-475, 1982.

Higgins, C.A., Conrath, D.W., and Dunn, E.V.: Provider Acceptance of Telemedicine Systems in Remote Areas of Ontario. *Journal of Family Practice* 18:285-289, 1984.

Ho, B.K.T., Taira, R.K., Steckel, R.J., and Kangarloo, H.: Technical Considerations in Planning a Distributed Teleradiology System. *Telemedicine Journal* 1:53-65, 1995.

Hoehn, M.M., and Yahr, M.D.: Parkinsonism: Onset, Progression and Mortality. *Neurology* 17:427-442, 1967.

House, A.M., and Keough, E.M.: Distance Health Systems—Collaboration Brings Success: The Past, Present, and Future of Telemedicine in Newfoundland. Paper presented at Conference on Information Technology in Community Health, Victoria, BC. October 1992.

House, M., Keough, E., Hillman D., et al.: Into Africa: The Telemedicine Links Between Canada, Kenya and Uganda. *Canadian Medical Association Journal* 136:398-400, 1987.

House, A.M., and Roberts, J.M.: Telemedicine in Canada. *Canadian Medical Association Journal* 117:386-388, 1977.

Houtchens, B.A., Clemmer, T.P., Holloway, H.C., et al.: Telemedicine and International Disaster Response: Medical Consultation to Armenia and Russia Via a Telemedicine Spacebridge. *Prehospital and Disaster Medicine* 8:57-66, 1993.

Hubble, J.P.: Interactive Video Conferencing and Parkinson's Disease. *Kansas Medicine* 93:351-352, 1992.

Hubble, J.P., Pahwa, R., Michalek, D.K., et al.: Interactive Video Conferencing: A Means of Providing Interim Care to Parkinson's Disease Patients. *Movement Disorders* 8:380-382, 1993.

Hudson, H.E., and Parker, E.B.: Medical Communication in Alaska by Satellite. *New England Journal of Medicine* 289:1351-1356, 1973.

Iglehart, J.K.: The American Health Care System: The End Stage Renal Disease Program. *New England Journal of Medicine* 328:366-371, 1993.

Jones, P.K., Jones, S.L., and Halliday, H.L.: Evaluation of Television Consultations Between a Large Neonatal Care Hospital and a Community Hospital. *Medical Care* 18:110-116, 1980.

Justice, J.W., and Decker, P.G.: Telemedicine in a Rural Health Delivery System. *Advances in Biomedical Engineering* 7:101-171, 1979.

Kelly, P.J.: Quantitative Virtual Reality Surgical Simulation, Minimally Invasive Stereotactic Neurosurgery and Frameless Stereotactic Technologies. Paper presented at Medicine Meets Virtual Reality II: Interactive Technology and Healthcare Conference. San Diego. January 1994.

Lang, A.E.T., and Fahn, S.: Assessment of Parkinson's Disease. In Munsat, T.L., ed.: Quantification of *Neurologic Deficit.* Boston. Butterworths, 1989.

Laughlin, L.W., and Legters, L.J.: Special Report: Disease Threats in Somalia. *American Journal of Tropical Medicine and Hygiene* 48:6-10, 1993.

Levinsky, N.G.: The Organization of Medical Care: Lessons From the Medicare End Stage Renal Disease Program. *New England Journal of Medicine* 329:1395-1399, 1993.

Llewellyn, C.H.: The Role of Telemedicine in Disaster Medicine. *Journal of Medical Systems* 19:29-34, 1995.

Lovett, J.E., and Bashshur, R.L.: Telemedicine in the USA: An Overview. *Telecommunications Policy* 3-14. March 1979.

Mattioli, L., Goertz, K., Ardinger, R., et al.: Pediatric Cardiology: Auscultation From 280 Miles Away. *Kansas Medicine* 93:326-350, 1992.

Menolascino, F.J., and Osborne, R.G.: Psychiatric Television Consultation for the Mentally Retarded. *American Journal of Psychiatry* 127:157-162, 1970.

Minsky, M.: *Toward a Remotely-Manned Energy and Production Economy.* A.I. Memo No. 544. Cambridge, MA. Massachusetts Institute of Technology Artificial Intelligence Laboratory, 1979.

Moore, G.T., Willemain, T.R., Bonanno, R., et al.: Comparison of Television and Telephone for Remote Medical Consultation. *New England Journal of Medicine* 292:729-732, 1975.

Murphy, R.L.H., and Bird, K.T.: Telediagnosis: A New Community Health Resource. *American Journal of Public Health* 64:113-119, 1974.

Murphy, R.L.H., Block, P., Bird, K.T., and Yurchak, P.: Accuracy of Cardiac Auscultation by Microwave. *Chest* 63:578-581, 1973.

Murphy, R.L.H., Fitzpatrick, T.B., Haynes, H.A., et al.: Accuracy of Dermatologic Diagnosis by Television. Archives of Dermatology 105:833-835, 1972.

Nicogossian, A.E.: Final Project Report: U.S.-U.S.S.R. Telemedicine Consultation Spacebridge to Armenia and Ufa. Paper presented at the Third U.S.-U.S.S.R. Joint Working Group on Space Biology and Medicine, Moscow and Koslovodsk, U.S.S.R. December 1989.

Ong, K., Chia, P., Ng, W.L., and Choo, M.: A Telemedicine System for High-Quality Transmission of Paper Electrocardiographic Reports. *Journal of Telemedicine and Telecare* 1:27-33, 1995.

Padeken, D., Sotiriou, D., Boddy, K., and Gerzer, R.: Health Care in Remote Areas. *Journal of Medical Systems* 19:69-76, 1995.

Palmer, R.H.: Confronting Special Implementation Issues: The Epidemiology of Quality Problems. In Donaldson, M.S., Harris-Wehling, J., and Lohr, K.N., eds.: *Medicare: New Directions in Quality Assurance.* Washington, D.C. National Academy Press, 1991.

Park, B., and Bashshur, R.: Some Implications of Telemedicine. *Journal of Communication* 25:161-166, 1975.

Pedersen, S., Hartviksen, G., and Haga, D.: Teleconsultation of Patients with Otorhinolaryngologic Conditions. *Archives of Otolaryngology and Head and Neck Surgery* 120:133-136, 1994.

Pedersen, S., and Holand, U.: Tele-Endoscopic Otorhinolaryngological Examination: Preliminary Study of Patient Satisfaction. *Telemedicine Journal* 1:47-52, 1995.

Perednia, D.A.: Telemedicine System Evaluation and a Collaborative Model for Multi-centered Research. *Journal of Medical Systems* 19:287-294, 1995.

Perednia, D.A., and Allen, A.: Telemedicine Technology and Clinical Applications. *Journal of the American Medical Association* 273:483-488, 1995.

Perednia, D.A., and Brown, N.A.: Teledermatology: One Application of Telemedicine. *Bulletin of the Medical Library Association* 83:42-47, 1995.

Perednia, D.A., and Grigsby, J.: Telephones, Telemedicine, and a Rational Reimbursement Policy. Under review, 1995.

Physician Payment Review Commission: *Annual Report to Congress.* Washington, DC., 1995.

Pool, S.L., Stonsifer, J.C., and Belasco, N.: Application of Telemedicine Systems in Future Manned Space Flight. Paper presented at Second Telemedicine Workshop, Tucson, AZ. December 1975.

Preston, J., Brown, F.W., and Hartley, B.: Using Telemedicine to Improve Health Care in Distant Areas. *Hospital and Community Psychiatry* 43:25-32, 1992.

Puskin, D.S.: Opportunities and Challenges to Telemedicine in Rural America. *Journal of Medical Systems* 19:59-67, 1995.

Puskin, D.S., and Sanders, J.H.: Telemedicine Infrastructure Development. *Journal of Medical Systems* 19:125-129, 1995.

Rayman, R.B.: Telemedicine: Military Applications. *Aviation, Space, and Environmental Medicine* 63:135-137, 1992.

Riggs, R.S., Purtilo, D.T., Connor, D.H., and Kaiser, J.: Medical Consultation via Communications Satellite. *Journal of the American Medical Association* 228:600-602, 1974.

Rinde, E., Nordrum, I., and Nymo, B.J.: Telemedicine in Rural Norway. *World Health Forum* 14:71-77, 1993.

Sanders, J.H.: Increasing Productivity Through Telecommunications. Proceedings of the NSF Symposium on Research Applied to National Needs (RANN-2). November 1976.

Sanders, J.H.: Telemedicine: Challenges to Implementation. Paper presented at the Rural Telemedicine Workshop, Office of Rural Health Policy. Washington, DC. November 1993.

Sanders, J.H., and Samsor, L.: Telecommunications in Health Care Delivery. Proceedings of the First Symposium on Research Applied to National Needs (RANN) 167-169. National Science Foundation, 1973.

Sanders, J.H., and Tedesco, F.J.: Telemedicine: Bringing Medical Care to Isolated Communities. *Journal of the Medical Association of Georgia* 82:237-241, 1993.

Satava, R.M.: Robotics, Telepresence and Virtual Reality: A Critical Analysis of the Future of Surgery. Minimally Invasive Therapy 1:357-363, 1992.

Satava, R.M.: Virtual Reality Surgery Simulator: The First Steps. *Surgical Endoscopy* 7:203-205, 1993.

Schroeder, S.A.: The Institute of Medicine Report. In Donaldson, M.S., Harris-Wehling, J., and Lohr, K.N., eds.: Medicare: *New Directions in Quality Assurance.* Washington, D.C. National Academy Press, 1991.

Siderfin, C.D.: Low-Technology Telemedicine in Antarctica. *Journal of Telemedicine and Telecare* 1:54-60, 1995.

Smego, R.A., Khakoo, R.A., Burnside, C.A., and Lewis, M.J.: The Benefits of Telephone-Access Medical Consultation. *Journal of Rural Health* 9:240-245, 1993.

Sobczyk, W.L., Solinger, R.E., Rees, A.H., and Elbl, F.: Transtelephonic Echocardiography: Successful Use in a Tertiary Pediatric Referral Center. *Journal of Pediatrics* 122:S84-S88, 1993.

Solow, C., Weiss, R.J., Bergen, B.J., and Sanborn, C.J.: 24-Hr. Psychiatric Consultation Via TV. *American Journal of Psychiatry* 127:1684-1687, 1971.

Sparks, K.E., Shaw, D.K., Eddy, D., et al.: Alternatives for Cardiac Rehabilitation Patients Unable to Return to a Hospital-Based Program. *Heart and Lung* 22:298-303, 1993.

Spiller, R.E., Hellstein, J.W., and Basquill, P.J.: Radiographic Support in Highly Mobile Operations. *Military Medicine* 155:486-489, 1990.

Straker, N., Mostyn, P., and Marshall, C.: The Use of Two-Way TV in Bringing Mental Health Services to the Inner City. *American Journal of Psychiatry* 133:1202-1205, 1976.

Turner, J., Brick, J., and Brick, J.E.: MDTV Telemedicine Project: Technical Considerations in Videoconferencing for Medical Applications. *Telemedicine Journal* 1:67-71, 1995.

Wasson, J., Gaudette, C., Whaley, F., et al.: Telephone Care as a Substitute for Routine Clinic Follow-Up. *Journal of the American Medical Association* 267:1788-1793, 1992.

Weinstein, R.S., Bloom, K.J., and Rozek, L.S.: Telepathology: Long-Distance Diagnosis. *American Journal of Clinical Pathology* 91:S39-S42, 1989.

Wittson, C.L., Affleck, D.C., and Johnson, V.: Two-Way Television Group Therapy. *Mental Hospital* 12:22-23, 1961.

Wittson, C.L., and Benschoter, R.: Two-Way Television: Helping the Medical Center Reach Out. *American Journal of Psychiatry* 129:136-139, 1972.

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