# Evaluation of the Effectiveness of Portable Low-Bandwidth Telemedical Applications for Postoperative Followup: Initial Results

James C Rosser Jr, MD, FACS, Ruediger L Prosst, MD, Edgar B Rodas, MD, Ludie E Rosser, BS, Michinori Murayama, MD, PhD, Harold Brem, MD

**Background:** The idea of using telemedical applications to evaluate patients remotely is several decades old. It has already been established that x-ray images (and magnetic resonance images) can be transferred using a personal computer and a modem, and many other such applications have been implemented. Over the past 50 years the expense and technical demands of the equipment involved in telemedicine have hindered its widespread deployment. The purpose of this study is to evaluate the ability of a mobile, low-bandwidth telemedicine platform to achieve real-time postoperative visits in the home.

**Study Design:** This evaluation was designed to evaluate the feasibility of performing a real-time clinical visit with computer and telecommunications hardware and software. A nurse and medical student (for information gathering only) made postoperative visits at patients' homes while the physician stayed at the office. Clinical evaluations were performed by using low-resolution and frame-rate video, high-resolution still images, and simultaneous telephony over a standard telephone line. These remote visits were followed by a standard visit in the office. Eleven patients were included, all of whom had undergone various laparoscopic procedures. They lived 5 to 240 miles from their surgeon. Efficiency was measured by recording the time required to capture and send data required by the physician to make a clinical decision. The time expense was measured at both the patients' and physician's locations. Technical issues were evaluated and patient satisfaction was assessed by standardized objective questionnaires. The accuracy of the evaluation at the remote visit was determined with a standard office visit.

**Results:** No technical problems were observed. The mean total time of the housecall at the remote site was 86 minutes (range 60 to 160 minutes) and at the base station site was 41 minutes (range 21 to 71 minutes). After personnel became familiar with the system, the last three visits averaged 61 and 25 minutes at the two sites, respectively. This corresponds favorably with current time requirements for visiting nurses and office visits. The patients were highly satisfied with the home visit and, on average, rated the experience as 4.8 out of a maximum of 5.

**Conclusions:** Followup visits in patients' homes after laparoscopic procedures can be accomplished by transmitting simultaneous voice, low-resolution video, and high-resolution still images to accurately perform postoperative evaluations over standard telephone lines, with time requirements and clinical accuracy similar to those of standard visits. (J Am Coll Surg 2000;191: 196–203. © 2000 by the American College of Surgeons)

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From the Department of Surgery, Yale University, New Haven, CT.
Correspondence address: James C Rosser Jr, MD, FACS, Department of Surgery, Yale Endo-Laparoscopic Center, 40 Temple St, Suite 3A, New Haven, CT 06510-8062.

The benefits of using telemedicine applications to evaluate patients and initiate treatment protocols remotely have been contemplated for several decades. It was 50 years ago that Gershon-Cohen[1] began to send x-rays using facsimiles over a distance of 28 miles by using simple telephone services to transmit the images. He wrote that engineering im-


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provements would be necessary to reduce the costs sufficiently to make the procedures practical. But, 50 years later, the high expense and the requirement of technically demanding equipment still have slowed the practical usefulness of telemedicine, and many projects have come and gone without an important impact on utilization rates. Previous projects failed mostly because of their inability to justify these programs on a cost-benefit basis.[2] At present, patients benefit most from programs established in oncology,[3] dermatology,[4] rheumatology,[5] cardiology,[6,7] radiology,[8-11] geriatrics,[12] otorhinolaryngology,[13] psychiatry,[14,15] and fetal medicine.[16] Many of these programs continue to require expensive, complicated technology.

It has already been established that x-ray images, including magnetic resonance images, can be transferred with a standard personal computer and a modem.[8-11] Other projects use standard telephone lines to convey the results of echocardiography examinations to an on-call cardiologist's portable computer.[6,7] Photographs of histopathologic specimens can be transmitted efficiently and routinely over copper telephone lines.[15] National and international networks also exist for high-resolution, static imaging telepathologic diagnostics.[16] These projects are mostly based on immobile telecommunications equipment that is not suited for field deployment, and the transfer time of the images is so long that a real-time doctor–patient interaction is not possible.

The ability to transfer data is dependent on the bandwidth that is available between two systems, and different telecommunications modalities have different levels of bandwidth. The higher or broader the bandwidth, the more costly and less easily available a technologic application will be. The higher cost is due not only to transmission rates, but also to hardware costs, for standard videoconferencing equipment may cost from $30,000 to $70,000. This hardware cost issue is being addressed rapidly and will not be an obstacle in the years to come. The T-1–level bandwidth equals $1.54 \times 10^3$ kilobytes per second (Kb/s). This high-bandwidth icon was at one time the standard for full-motion videoconferencing, which is at the heart of most telemedical applications.[16] ISDN (Integrated Services Digital Network) lines have become available and offer the capability of having fractionated T-1 bandwidths in increments of 64 Kb/s. This option offers a more cost-effective package with the desired amount of bandwidth on demand and has growing availability throughout the United States and abroad. But installation costs, maintenance, and utilization charges limit its widespread availability in most homes. This brings us to standard telephone service lines, which represent the most widespread, readily available telecommunications conduit in the world today. Their drawback is that they have very limited bandwidth. Download capacity theoretically can be as high as 56 Kb/s with special modems. Transmission or upload times are fairly fixed at 28.8 to 33.6 Kb/s. These transmission rates are not high enough to allow real-time, full-screen, high-resolution video teleconsultations. This bandwidth allows only partial-screen, low-resolution video at three to seven frames per second. Full-motion video is 25 to 30 frames per second. In addition, at this bandwidth a 1-megabyte still image can take up to 20 minutes to transmit.

Despite these current drawbacks, several advances are converging that will lower some of these traditional hurdles. In addition, proprietary software compression algorithms are able to decrease the size of transmission traffic to greatly improve data transfer rates, quality, and motion. With these technical improvements, real-time teleconsultations in homes over standard telephone lines are within the realm of possibility. Ricci and associates[17] and Wirthlin and colleagues[18] showed that the use of computing and telecommunications in the "store and forward" mode could be deployed effectively to allow remote clinical evaluations. These studies represent rare data presented on the subject.

Despite the tremendous strides in other disciplines, telemedicine applications in surgery have not been well developed. Telementoring, the process of guiding an inexperienced surgeon through advanced procedures from a remote site, has been helpful,[19-21] but other applications have not been well developed. Reluctance to apply telemedicine to surgery stems from several concerns. Specifically, it is unknown whether the surgeon can accurately assess the patient in a "remote mode" with a high patient acceptance rate and cost effectiveness. This study evaluates the ability of a mobile, low-

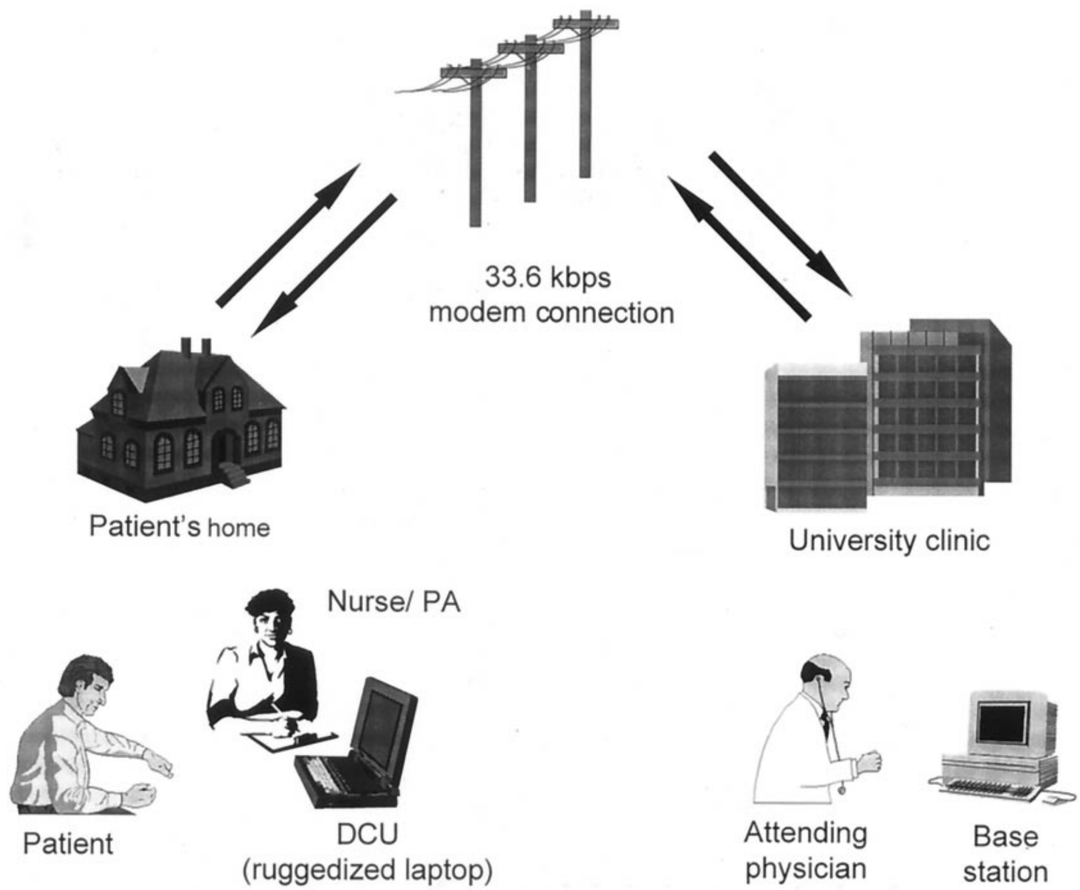


**Figure 1.** Overview of the telecommunication link. DCU, distant care unit.

bandwidth telemedicine platform to achieve real-time postoperative visits in patients' homes.

## METHODS

An electronic housecall was performed for 11 patients after their laparoscopic operations (eg, Nissen fundoplication; splenectomy). The mean age of the five men and six women was 51.7 years (range 28 to 71 years). The approximate distance between the patients' homes and the base station at Yale University ranged from 5 to 240 miles. The Distant Care (Telemedicine Corporation of America, Chantilly, VA) mobile, low-bandwidth telemedical system was used to accomplish the home visits. It consists of remote and base components (Fig. 1).

### Distant care remote unit

The remote unit is designed around a "ruggedized" Panasonic CF-25 (Panasonic Personal Computer Company, Secaucus, NJ) portable computer with a Pentium Processor (133 MHz), 24 MB of RAM, a 1.35-GB hard disk drive, and a 10.4-inch TFT color LCD screen. The TDK DFV3400 33.6-Kb/s PCMCIA card (TDK Systems, Nevada City, CA) was used as the modem. For still-image capturing, the Kodak DC50 zoom camera (Kodak, Rochester, NY) was used. The Kenwood PCMCIA (Kenwood, Tokyo, Japan) videoconference system was used to capture and transmit low-resolution video. Proprietary software manipulation of Microsoft Outlook and NetMeeting (Microsoft, Redmond, WA) and Telemedicine Corporation—Visitran (Med Vision, Minneapolis, MN) telemedical software rounded out the software package. All of the information management and simultaneous voice and data transactions were handled by these software solutions.

### Base station

The base desktop is a Pentium 166-MHz, 64-MB RAM, 6.4-GB hard drive, PC, Mini-tower NT

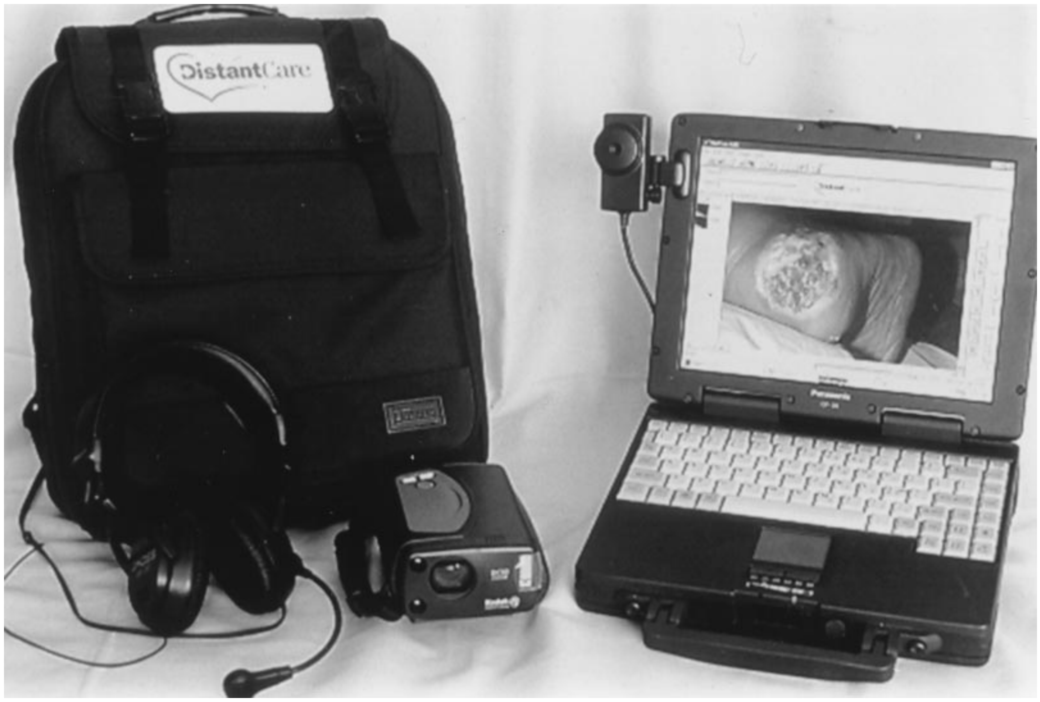


**Figure 2.** Equipment components.

Server 5.0 with a 33.6-Kb/s modem and an SVGA 17-inch multiscan monitor. With the rapid advancement and decrease in the cost of technology, the computing parameters have changed since the time of early development for both computers. The base has the capability of handling four incoming consultations at once. It has the same software package as the remote unit, which allows annotation on the image that is instantly shared by the base and remote site. Annotation serves as an excellent teleguidance tool to direct treatment and also helps to educate the health care provider and the patient.

A medical student and a nurse were sent to each patient's house to perform a remote examination of the patient. The visits were conducted on the patient's second postoperative visit. All patients received detailed information about the project and signed a consent form. Important patient information was recorded in the computer's database, and vital signs were taken with digital devices. Several photographs were taken with a Kodak DC50 camera based on a preplanned protocol (Figs. 2, 3), including the digital readouts of the vital-sign devices (pulse, BP, and temperature) and each abdominal quadrant with oblique views. The pictures were loaded into the laptop. After securing a modem-to-modem connection with the base station, personnel initiated audio and video contact. The patient–doctor interaction was established with audio and low-bandwidth video. Next, the video and audio were disengaged, and still images were transmitted rapidly from the remote to the base, which were then reviewed and saved by the surgeon. Images of interest were selected, and the "white boarding" (image sharing) feature was engaged. Then the surgeon and the on-site team viewed the same image, and areas of interest were highlighted with annotation tools. The findings were discussed and the surgeon formulated a treatment plan. The video link was then reestablished, and the surgeon discussed the findings and treatment plan with the patient and the nurse. This entire process was accomplished with a modem-to-modem connection using only one telephone line. This avoids the privacy issues associated with use of the Internet. The patient was seen in the office 1 week later for a standard followup visit for clinical correlation. The clinical course documented by the cybervisit correlated with the standard visit in all cases. No clinical evaluation errors were encountered.

A log of all missions was maintained to be able to track all technical concerns. Equipment setup

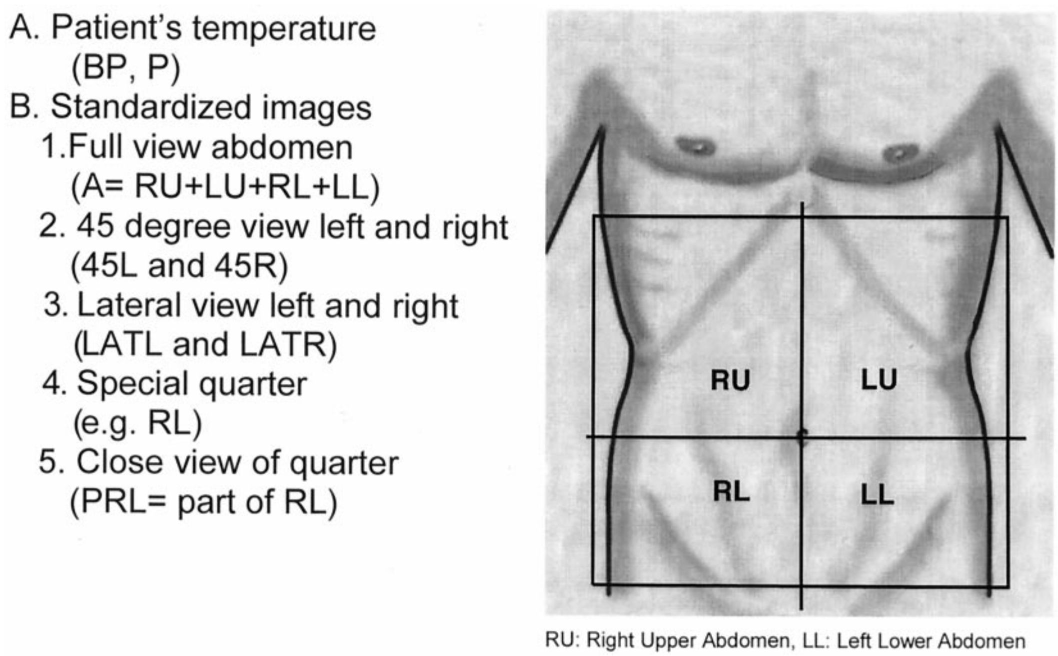


**Figure 3.** Protocol for images to evaluate abdominal-wall wounds. P, pulse.

time, number of images required, computer link time, transmission times of the images, and failures were documented.

All patients were required to complete a questionnaire at the end of the consultation. The questionnaire contained details such as acceptance of the technology, satisfaction with the medical examination, consciousness of accessibility to the remote surgeon, privacy and confidentiality concerns, opinions about future applications of this type of care giving, and an overall statement about the project.

## RESULTS

The mean total time of the housecall at the remote site was 86 minutes (range 60 to 160 minutes) and at the base station site was 41 minutes (range 21 to 71 minutes). The average of the last three visits reflected a more authentic assessment of the time requirements for a mission (61 minutes remote and 25 minutes at the base). It should be kept in mind that this study was done within the restraints of a rigid data-collection protocol, which extended the visit time. It took an average of 3.8 minutes (range 2.0 to 6.0 minutes) to set up the equipment and 115 seconds (range 20 to 255 seconds) to connect both computers. The average time to transmit an image was 20 seconds. The shortest duration of a computer link was 17 minutes and the longest was 67 minutes (mean 37 minutes). There is a learning curve for the home care professional (Fig. 4), which is demonstrated by the decreasing visit times. During the examinations, 5 to 10 images were transmitted (mean 8.7).

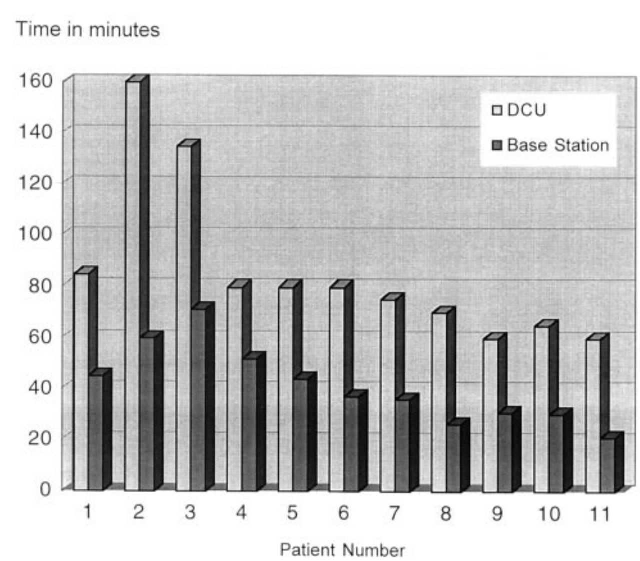


**Figure 4.** Time of the visit at the base and remote station. DCU, distant care unit.

The overall satisfaction grade of the electronic housecall (on a scale of 5 = very satisfied to 1 = very dissatisfied) ranged from 5.0 to 4.0, with an average of 4.8. All patients felt comfortable during the examination and thought that their privacy and confidentiality were adequately protected. No patient complained that the housecall was too impersonal. Only one patient stated a concern about the effect of this technique on the surgeon's ability to make a clinical assessment.

## DISCUSSION

One of the most debated issues surrounding the use of telemedicine is whether the doctor–patient relationship can be established and maintained with a high level of patient satisfaction. This has been proved in clinical studies, but the telecommunications platforms used high-bandwidth protocols (384 Kb/s, $1.54 \times 10^3$ Kb/s) composed of systems with full-screen, full-motion, high-resolution video and duplex telephony. In comparison, with the limited bandwidth of standard telephone lines, the video is significantly inferior. Video is presented in a $2.5 \times 2.5$-inch window at three to seven frames per second. In addition, the image is of low resolution. The perception of full motion occurs at 25 to 30 frames per second. It is important to observe whether the doctor–patient relationship can be established and maintained under these circumstances. In this study, it is apparent that the patients did feel comfortable with the electronic housecall. Their overall satisfaction grade of the electronic housecall ranged from 5.0 to 4.0 (mean 4.8). Privacy and confidentiality issues were of no concern to the patients, and none of them complained that the housecall was too impersonal. Only one patient stated a concern about the lack of personal contact with the surgeon. As a result of this high level of satisfaction, we conclude that the low-resolution video with simultaneous voice transmission between the physician and the patient proved to be adequate in establishing a postoperative relationship.

Without the advantage of full-motion videoconferencing capability, it was questionable whether high-resolution still images transmitted with short data-transmission times could allow a dynamic real-time teleconsultation using "store and forward" technology. There was also a question of whether high-resolution still images could augment the low-resolution video image to allow accurate evaluations. Traditionally, "store and forward" technology allows transmission of data for the purpose of consultation in non–real time fashion. This protocol is usually reserved for situations in which remote and base sites have limited bandwidth but need to transfer large data files. The files can then be reviewed at the leisure of the provider after completion of the transmission. This mode of data transfer is especially advantageous when there is a mismatch between consultation and provider availability. Because of the aforementioned features, this type of consultation method is usually not appropriate for dynamic real-time interaction.

Captured images from the video camera were evaluated, and the resolution was not adequate. Because of this, a digital still camera was used with a resolution of $758 \times 580$ pixels. The increased resolution was more than adequate, but the files can be as large as 1 megabyte. Transmission times for such files can be as long as 1 hour, but with the proprietary algorithms of the Distant Care System, the average time was 20 seconds per image. The ability of the remote and base sites to share images with annotation capability almost in real time was pivotal for teleguidance, which is necessary to maximize the evaluation process. Simultaneous voice transmission was also pivotal in the consultation. The effectiveness of the visit was excellent, and the followup visits agreed with the initial distant consultation.

Another challenge that prevents the successful deployment of telemedical applications is the maintenance of standard visit times and personnel service-delivery profiles. The average time for the "electronic visit" was 86 minutes for the home visit and 41 minutes for the base consultation. This includes the time consumed by data gathering for the purpose of this study. After the initial visits, the times decreased to as low as 60 minutes and 20 minutes, respectively. With the base able to process four consultations at once, the physician could see a patient every 20 minutes by coordinating the visits of clinical technicians. This time allotment is similar to that currently used by clinicians for standard office visits. The only difference is that the clinic is in "cyberspace."

There are several factors driving the need to mature new methods to take care of patients. These include the need for rapid development and deployment of new procedures, dramatic reduction of hospital stays with the same level of patient quality assurance, and patient treatment plans that encourage compliance without the need for the patient to travel or to disrupt personal and family schedules. Decreased patient travel can blunt the devastating effect that acute and chronic illnesses have upon economic productivity. In addition, it can become a true preventive-medicine strategy that ultimately will provide a clinical-outcome and cost-containment advantage. One vision is that nurses or paramedics can be equipped with mobile telecommunications devices to allow direct in-home access to the patient's physician. We think that the greatest advance can be realized in the training and empowerment of a new cost-effective component in the health care work force. Technicians who are trained in very focused medical areas and controlled remotely by more experienced and extensively trained mentors could offer services with a similar quality-assurance expectation of standard practices. This strategy fits into the current managed care environment. Surgeons could take care of more people with less personnel cost and reduced infrastructure requirements, with similar or better patient outcomes and patient satisfaction. We anticipate that this application will be used in the followup of patients with chronic debilitating diseases, complex wounds, and orthopedic rehabilitation, and in evaluations of emergency situations.[22] This optimism is supported by the fact that home health care services have been expanding rapidly over the last 10 years. An estimated 500 million housecalls were made in 1995 by nurses and other health aides, at an average cost of $63, for a total of $31.5 billion.[23] Health care experts and analysts predict that in the next decade, up to 20% of all home health care will be delivered by way of telemedicine links. Similar to the deployment of cellular telephone technology, the cost of the technology will decline at an ever-increasing pace. Then the barrier of hardware or communication costs will be eliminated. Service-delivery organizations and assisting business ventures will spring up to help health care providers keep as profit as much as possible of the managed care global health services delivery fund.

In conclusion, this initial clinical evaluation of a mobile, low-bandwidth telemedical application leads us to the strong belief that it can facilitate postoperative followup patient consultations. In the future, similar technology can be deployed permanently in the home that would allow teleconsultations to occur at the convenience of the patient. But with more than 50% of Americans unable to program their VCRs, the public needs to be introduced to this concept of "cybercare" with the assistance of personnel. The health care provider will serve as the interface between the technology and the physician. In the future, it is a certainty that patients will conduct their own visits with the help of an in-house "holographic physician" or "compu-medic." Mobile, low-bandwidth telemedical applications offer the advantage of delivery of more information than a traditional voice followup and increase the size of the patient "safety net" as we seek to aggressively cut back on patient care in the hospital. Although the results of this experience are encouraging, these preliminary results should be confirmed by a larger study that also thoroughly evaluates the cost effectiveness to the health care system.

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