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Chapter 2

Clinical Applications in Telemedicine/Telehealth

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

THE STATE OF THE ART IN CLINICAL APPLICATIONS

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

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

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

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

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

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

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

MATURE APPLICATIONS: TELERADIOLOGY AND TELEPATHOLOGY

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

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

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

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

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

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

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

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

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

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

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

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

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

MATURING APPLICATIONS: TELEPSYCHIATRY, TELEDERMATOLOGY, TELECARDIOLOGY, AND TELEOPHTHALMOLOGY

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

Telepsychiatry

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

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

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

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

Teledermatology

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

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

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

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

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

Telecardiology

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

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

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

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

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

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

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

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

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

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

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

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

Teleophthalmology

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

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

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

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

EMERGING APPLICATIONS: TELESURGERY, TELEPEDIATRICS, AND EMERGENCY MEDICINE

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

Telesurgery

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

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

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

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

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

Telepediatrics

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

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

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

Emergency telemedicine

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

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

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

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

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

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

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

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

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

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

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

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

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

SPECIAL APPLICATIONS AND SETTINGS

Rare diseases

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

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

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

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

Telemedicine in the home

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

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

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

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

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

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

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

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

RECOMMENDATIONS FOR FUTURE ACTION AND RESEARCH

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE 2. PROPOSED STAGES FOR CLINICAL TELEMEDICINE RESEARCH

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

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

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

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

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

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

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

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