PEER REVIEW PAPER

Telemedicine: I Can See the Highway, But Where Is the Ramp?

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Introduction

In a remote village in Central America, an otherwise unmanaged child's infection can take a turn for worse if not for the long distance diagnosis capacity brought about by the recently installed telemedicine system between Zacapa, Guatemala, and Houston, Texas, where subspecialists in the field of Pediatric Dermatology viewed the wound and prescribed the critically needed treatment.

Recent developments in the telecommunications and the information technology fields hold the promise of improved access to and the better utilization of health-care-related resources. In addition to these developments, the deployment of interactive distant training programs offers an opportunity to decrease the knowledge gap between the leading academic medical centers where new medical knowledge is continuously being discovered and the remote health-care practitioners who find themselves pressed to deliver quality care that meets the needs of their communities in a competitive environment of limited resources. Telemedicine is creating new opportunities for imagining the possibility of a more efficient and accessible health-care delivery system. Telemedicine is just the tool, not the end, by which to negotiate and overcome barriers on the road to the delivery of quality services that the present system cannot deliver as effectively. The developments of modern telecommunications and information technology tools present a radical opportunity to change the health-care delivery infrastructure from the ground up.

The implementation of TeleHealth programs in such an environment is supported by enthusiastic approaches, but not with enough planning tools. There is a need to understand how to best adopt the advantages offered through intelligent communications that limitlessly extends the boundary of our senses, records, activities, and outreach. *At its basic application, telemedicine can take the distance out of caring.* Clinical needs, including the provision for innovative quality continuing education, is one of the programs' prime focuses. However, once we move beyond the clinic, there are the financial, legal, and engineering implications of telemedicine that challenge the status quo. *If telemedicine is going to become a staple of medical practice in our planet, a massive re-engineering of the national and international telecommunications infrastructure, reimbursement legislation, and clinical practices will be required.*

There are over 150 telemedicine programs in operation today. It is estimated that 60 percent of them are less than six years old[1], representing a relatively new modality in the health-care delivery system, where the vast majority of the providers are still debating the appropriate entry course and the following regulatory and sustainability issues. This paper reviews the evolution and the major issues to consider before embarking on a telemedicine program.

Same Problems Different Solution

The Center for TeleHealth (CTH), one of the first telemedicine program to focus solely on the extension of Pediatrics subspecialty services, is the result of a collaborative program between the Texas Children's Hospital and the Baylor College of Medicine. While the Center was created for the specific goal of linking the institution's expertise to remote communities in Texas as well as globally, it would not have enjoyed the executive and medical faculty's support if it were not for the success demonstrated during its initial applications, which were the result of using video engineering concepts to solving intra-hospital problems. It required the installation of a video network for the transmission of real-time information transmission of echocardiography to the locations where the experts were available, the cardiology reading area. Soon, other problems were solved with similar measure of success. The subspecialty coverage of a remote clinical area, the newborn nursery, successfully tested the provision of remote video monitoring of babies by neonatalogists.[2]

While new knowledge is being discovered and acquired at an accelerated pace, specifically in the field of diagnostic and therapeutic medicine, within the major cluster of the

academic medical centers the care provider who practices in the remote and at times rural area or in the overburdened urban clinics has yet to realize how best to absorb and deploy this new information. TeleHealth is providing a unique opportunity to restructure the dissemination of knowledge methodology used in today's health-care delivery system in a way that will distribute specific competencies to the most needed environment — the best practice at the point of care. This focus will allow our society to move from a reactive mode of delivering care toward a life-long health management where individual accountability, preventive medicine and customized wellness programs are integral components of a new health management methodology.

The Telemedicine Evolution

Telemedicine is not a new entity as most may think. Rather, it enjoys over seventy years of historical evolution. The April 1924 issue of the *Radio News Magazine* showed a drawing of physician viewing a patient over shortwave radio set that included a television like display. More realistically, the early programs in the 1950s and 1960s were highlighted with some success by the Nebraska Psychiatric Instate and the Massachusetts General Hospital and Boston's Logan International Airport link[3]. However, these programs lack the ability to deliver sustained satisfaction to the health-care providers or to the patients involved. Following the invention of the color television and launching of satellites in 1965, Dr. Michael Debakey, the cardiovascular surgeon at the Baylor College of Medicine, started to incorporate video tools into the medical training program and was successful that year to broadcast the first live cardiac surgery from the operating rooms at the Methodist Hospital at the Texas Medical Center to Europe utilizing satellite transmission. Colleagues in Amsterdam viewed and heard Dr. DeBakey mentoring the procedure at the time a new technique for teaching cardiac surgical intervention.

The investment of the United States Army and of the Federal government in the late 1980s and early 1990s in the integration of better telemedicine tools placed a focus on the rural communities and the need to extend care to the internationally deployed forces. These efforts provided the initial impetus for today's telemedicine programs. The new modality, namely the Internet, provided another example of how the barrier of distance can be overcome by having access to tools that enjoy, by now, a much more ubiquitous communications platform to transmit information between any two distant locations anytime. In 1983, the first use of the Internet to disseminate medical information between participants took place at the Texas Medical Center and demonstrated the potential for scientific interactions that were untried before then. Not only can we now use satellites and telephone lines in order to deliver medical information, we have added the Internet and the provision for communication between two single points as well as the ability to share information among multiple sites simultaneously at an affordable cost.

The early applications of video engineering were essentially an attempt to overcome intra-hospital information flow "bottlenecks." The connection with remote rural communities was not attempted until sufficient experience had accumulated with intra-hospital transmission of video, with the available telecommunications services including the "last mile," the point between the shared infrastructure and user connectivity. Thus, we began in 1993 to take advantage of these opportunities and reach out with our educational and clinical programs beyond the confines of the Texas Medical Center reaching out 400 miles southwest of Houston to McAllen, Texas, near the Mexican border. The program then, as today, focuses on the extension of pediatric subspecialty expertise to communities in needs.

The growing acceptance of telemedical-based services is changing the way health-care is delivered and provides opportunities not available before. In a recent survey conducted by *Telemedicine Journal* of telemedicine service providers, almost 70 percent of the responders cited the need to increase access to specialty care as the major motivation for initiating remote inter active clinical service; while, 33 percent of the responders cited cost saving as the primary methodology for measuring the success of such a service[4]. While the service can be administered in a variety of platforms, the need to accommodate clinical requirements and appreciate technological limitations is universal. However, these requirements and limitations change from one program to another and from one location to another.

Successful development and implementation of telemedicine service is dependent upon the ability to focus on and address specific clinical needs, the integration of infrastructure with existing platforms, and the availability of a reliable and sufficient end-to-end broadband telecommunications service. In addition, a sensitivity to cultural preferences and compliance with legal issues has an impact on performance as well.

The Telemedicine System

Interactive computers and advanced telecommunications technologies are transforming every aspect of our life. Medicine is no exception. From virtual classrooms to simulation research, and from pharmaceutical dispensers to artificial organs replacements, advances are generating breakthrough applications that improve quality of life for an ever-growing number of people. Health-care providers and educators as constituents of this transformation era enjoy new opportunities created for their active participation in this transformation. When we review the positive impact that the integration of ostensibly independent patient-care services have on the efficient management of the total quality of care, of education, and of collaborative research, it is not surprising that telehealth deployment is on the rise. The forces that drive this phenomenon include:

- The need to manage the entire disease encounter,
- The desire to apply standard quality of care over a wider geographically distributed community,

- The escalation of customer expectations,
- Globalization of health-care and its support services,
- An increase in patient and provider convenience, and
- Users acceptance of the present technological competency.

TeleHealth can be envisioned as the practice of health-care delivery through the use of advanced communication technologies, computers, video instrumentation, and medical devices to exchange information and to deliver services that overcome the barriers of distance, time, and sociocultural differences. Specific applications include:

- Delivering medical services,
  - consultation or validation,
  - prevention,
  - diagnosis, and
  - treatment,
- Transferring medical data
- Education, and
- Collaborative research.

Current applications are classified as follows:

1. Initial screening/evaluation of patients,
2. Triage decisions and pre-transfer screenings,
3. Medical and surgical follow-up and medication review,
4. Consultation for primary care encounters,
5. Real-time subspecialty care consultation and planning,
6. Management of chronic diseases and conditions,
7. Extended diagnostic work-ups,
8. Review of diagnostic images, and
9. Preventive medicine and patient education.

In addition, we have successfully conducted real-time interactive clinical engineering seminars between Houston, Texas, and Riyadh, Saudi Arabia, and many other examples such the Visions of Health and Peace project, that, through the use of telemedical tools, demonstrated the promise of global biomedical partnership between Israel and the United States.

This is a critical opportunity for engineers to participate in supporting telemedicine program by demonstrating skill sets that can assert and establish the quantifiable level of service that assures an appropriate match between the fidelity of acquiring and delivering sound and video levels and the clinical requirements of the specific encounter and to service and support the operations of this complex system.

The Telemedicine Practice

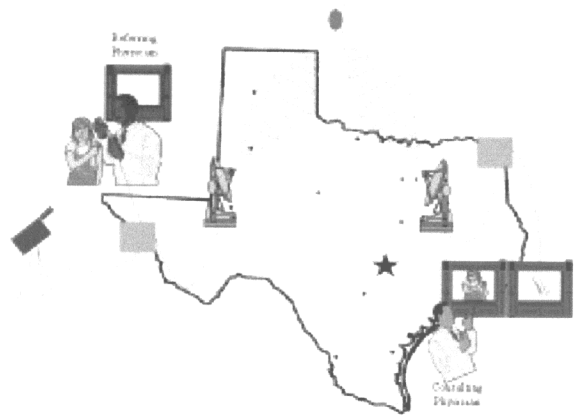
Telemedicine is the use of electronic information and communication technologies to provide and support health-care services when distance and time separate the participants.[5]

In its simplest form, telemedicine program consists of a site where a consulting physician is located (the hub) and a remote location (the spoke) where the referring physician and the patient are present. The consultation between the two peers, can take the form of diagnosis session or a second opinion session. The central hub can serve one or many spokes located at remote sites. The peer-to-peer review can be practiced in two different modalities; in real-time or in delayed time known as the "Store-and-Forward" mode. The difference between the modalities is the time span associated with the consultation protocol and the requirements of bandwidth.

Telemedicine practices can be categorized into variety of modalities, for example, according to type of services provided. Telemedical encounters can focus on clinical, educational or administrative program. A program that provides clinical encounters must comply with variety of regulatory guidelines and adhere to policies and procedures quite different than those required for the provision of educational services. Another categorization can be along the types or the size of network deployed, such as a point-to-point or a hub and multiple spokes system. However, the most popular categorization is done along the span of time within which the telemedical encounter begins, is reviewed, and completed. Most of the telemedicine programs operate in a synchronous mode, or in what is known as an interactive real-time full-motion encounter.

The other modality, Store-and-Forward, is an asynchronous mode where the refering physician and the patient do not have to be present at the time of the consultation together with the specialist. Rather, the referring physician gathers the patient information over a period of time utilizing a battery of diagnostic instruments, ranging from electronic stethoscope and X-ray images to pathological slides or cine fluoroscopy as shown in Figure 1. Other patient information, such as echocardiograms, can be incorporated as well as dictation of patient symptoms, family history, vital signs and demographics. This information is then packaged and moved as a completed file, electronic portfolio of the patient, to the consulting physician address at the hub. The transmission is encrypted to protect privacy and provide confidentiality of information. The consulting physician after being

Figure 1: Store-and-forward Telemdicine



alerted to the arrival of new electronic file will open the portfolio, review and then render a diagnosis and an opinion as to the management of this condition. The consultant will send it back to the referring physician for action.

There are several advantages to the Store-and-Forward modality. The patient does not have to be constrained by the schedules of the referring and the consulting physicians; the cost of telecommunications is minimal. On the other hand, the advantage of the real-time interactive mode is the high presentation quality that can be deployed and the ability to have multiple subspecialists participating simultaneously in management of the condition permits earlier and quicker decisionmaking processes.

Accompanying the increase in clinical applications, the appreciation for the minimum features level and fidelity provided by the various types of equipment and communication systems must become clearer in order to efficiently match capability with service needs. There is a critical opportunity for engineers and clinicians to participate in this process by defining the appropriate fidelity level that will best accommodate the clinical requirement.

There are additional important barriers still to overcome. These are the all critical financial, legal and technical barriers in telemedicine that include the following:

- Reimbursement,
  - Professional component,
  - Administrative component, and
  - Technical component.
- Liability,
- Licensure,
- Scheduling issues,
- Equality/universality of care,
- Patient/MD relationship,
- Appropriateness of application,
- Patient resistance,
- Abuse/over-utilization, and
- Confidentiality/privacy.

Transmission Test Conditions

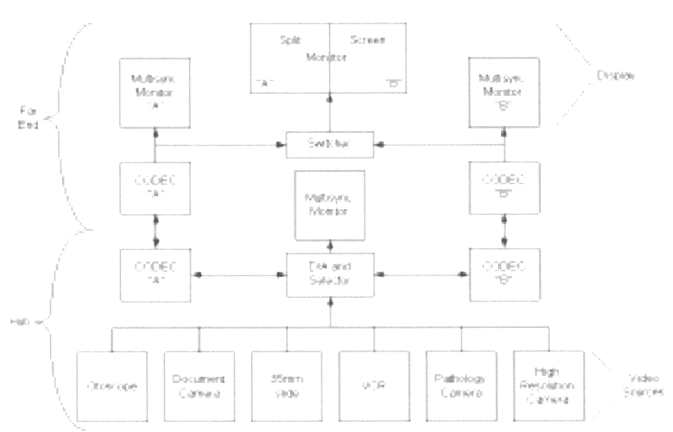
The evaluation of room-based telemedicine systems requires the commitment of many resources. There is a continual need to evaluate new evolving systems and technologies for an optimal match between patient and physician needs and technological capability in order to reach display fidelity optimization and to refine and standardize efforts. Our test was subjective in that our panel of experts was scoring competitors based on their impression and perception of "quality."

Seven years ago, we conducted an evaluation test to determine if and the magnitude of variation in video processing between the systems. Our testing protocol provided for a single video source to simultaneously broadcast its signal into two video conferencing systems. The video conferencing systems were designed to communicate with the video source at different bandwidths. The communication with video source was in real time over a protocol H.320 full T1 carrier service (1.544 Mbps) down to a ¼ T1 (386Kbps). The video source was changed from an ultrasound examination of a patient cardiac condition to a simulated patient with advanced Parkinson's disease. Other rapid and sudden movements against a large white background such as a downhill skiing race were used as well. A panel of senior medical sub-specialists observed the presentations and related their ability to render a medical opinion based on the quality of the displayed video and fidelity of the audio.

For a slow-moving event, such as an examination of skin conditions, a fraction of a T1 line was acceptable for rendering an opinion. However, for ultrasound examination and downhill skiing, the panel opinion was that only presentation quality of ½ T1 or better was sufficient to determined minute changes in the conditions presented. Proper lighting and the positioning of the camera during patient examination were also noted as critical for successful assessment of clinical conditions. Finally, the resolution and the overall size of the video screen were determined to have impact on the clinical acceptance of the telemedical encounter as well. The closer the display area was to a real-life size, the more the panel felt it was acceptable. Consequently, we conduct telemedical encounters where content included significant motion through only ½ T1 or better and employed the diagonal measure of 31" television sets.

Referring to the block diagram in Figure 2, all video sources were calibrated as to level and connected via a 1X8 video switcher (Selector). This enabled the selection of the various sources utilized in the evaluation at the request of the panel members. The output of the Selector was passed to a Distribution Amplifier (D/A) to compensate for losses resulting from the division of the video signals into two paths. The video signals were then passed to the two transmissions (Compressor/DECompressor) CODECs, "A" and "B". Equal lengths of transmission lines connected the Codecs

Figure 2. Telemedicine Evaluation Test



at the "near end" used for analog to digital conversion and subsequent compression and transmission of the signals to the Codecs at the "far end" used for reception, decompression and digital to analog conversion.

The output analog information from the two "far end" CODECs were connected to individual Multisync Monitors ("A" and "B"). The monitors, both of the same manufacturer and model, had been, prior to the evaluation, calibrated using an NTSC laboratory grade color bar generator and photometric color temperature and luminance meters. This calibration assured that both monitors were objectively as similar as possible in terms of picture quality. In addition, to provide a better side by side comparison of the two systems under evaluation a split screen monitor was employed. Video information from both Codec sources was split and sent through a switcher, enabling the side-by-side viewing of video information on a single monitor.

Immediately prior to the tests and evaluation, the Clinical Engineer in charge insured integrity of the "double blind" nature of the evaluation by making the final connections from the outputs of Codecs "A" and "B" to the monitor chain. This information was kept confidential until the evaluations were completed.

Resolution of these issues will extend our ability to exchange information and to increase interoperability with legacy systems. This will extend our capacity to engage in this evolution and to determine when it presents sufficient fidelity to deploy this service in the clinical setting. Finally, one must review the legal and regulatory aspects as well for the test described above in the domestic and global aspects.

The Telecommunications component

One of the fastest changing fields, telecommunications, is enabling existing and new platforms to exchange information and to support interaction through unique applications including the medical peripherals. Thus, the management of telemedicine program must incorporate the understanding of telecommunications technologies and the optimization of this component. The convergence of the digital and the analog transmission methods and the advantages of the various networking technologies requires an ability to evaluate and match the network needs with the capabilities of the available infrastructure. Clinical requirements need to be matched with technical capacity and supported by financial sustainability to influence the design and the implementation decisions when selecting the platform to be employed.

The many modes of communications support speed and bandwidth that ranges from the narrowband used for the plain old telephone system to the wideband application supported by integrated services digital network and satellite communications. Various selectable bandwidths, availability and level of service should be considered.

In selecting the telecommunications technology, one needs to clearly know how the network will be designed, what protocols are expected to be used, how much and how often data will be transmitted, and finally what is the budget for this program.

Video compression, a coding technique used to reduce the bandwidth required for the transmission of video images, is a developing science and recent developments are awaiting validation of its clinical acceptance and are still largely unsubstantiated by a conclusive body of research. There is a multitude of opinion on the topic, but very little hard data. The science of visual perception is unique in that it is a subjective function of the brain as well as the eye. No two individuals perceive the exact same image in exactly the same way. The threshold of persistence of vision and the measurable speed at which a motion picture or video screen ceases to flicker and begins to "move" may vary significantly among different observers under different lighting conditions. The eye and brain are thought to generally retain a visual impression for approximately 1/30th of a second. When viewed as a continuum, this collective retention is "seen" by the viewer as uninterrupted motion. It is significantly important, therefore, that the effect of the compression technique chosen for a telemedicine system will not further modify the assessment of the medical conditions being viewed.

SUMMARY

Telemedicine is an emerging industry with the potential to revolutionize the delivery of care to the benefit of health-care systems, providers, and patients. The application of electronically connected parties in provision of medical care and training has begun already to show some very exciting possibilities. Future expansion of telehealth systems will deliver services to the benefit of providers' networks, economy, and patients.

Recent developments and improvements in standards in the telecommunications and the information technology fields hold the promise of improved access to and better utilization of health-care related resources. Telemedical services can be deployed in a variety of platforms. Those platforms keep improving the capturing, transmission, and presentation of medical information. The deployment of any one or a combination of several platforms is dependent on such conditions as: clinical needs, level of staffing training, legal and cultural constrains, limited telecommunications infrastructure, regional economics, and the stage of technological development. Therefore, some applications are better suitable than others to support the needs of distant health-care providers.

Telemedicine systems must be tailored to the needs of the participating health-care system. Usually a tiered approach consisting of a mixture of real-time and store-and-forward technologies, wide bandwidth, and low frame rate is the optimal solution. With proper planning and the anticipated

advances in computing power, direct medical digital imaging and telecommunications will continue to increase the cost-effectiveness and expand the scope of telemedicine services.

Two modalities of practice are emerging: the real-time interactive mode and the Store-and-Forward mode.The combination of these modalities with the capabilities to exchange medical information as supported by the new telecommunications infrastructures places telemedicine at a central position for improving access to quality health-care by all.

We must continue to remove penalties, financial, legislative, and regulatory[6] ones in order to permit everyone in need to reach their goal by finding the ramp and get on the telemedicine highway.We need, however, to identify and to quantify the contribution of this transformation to the betterment of health for all.This challenge is going to be the next biggest obstacle for the field of TeleHealth.

Dr. Michael DeBakey put it best: "These technologies will allow us to improve the standards of health-care around the world ... providing an important opportunity for distant learning and for the dissemination of medical knowledge and support of this goal."

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