Telerehabilitation: State-of-the-Art from an Informatics Perspective

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Abstract

Rehabilitation service providers in rural or underserved areas are often challenged in meeting the needs of their complex patients due to limited resources in their geographical area. Recruitment and retention of the rural clinical workforce are beset by the ongoing problems associated with limited continuing education opportunities, professional isolation, and the challenges inherent to coordinating rural community healthcare. People with disabilities who live in rural communities also face challenges accessing healthcare. Traveling long distances to a specialty clinic for necessary expertise is troublesome due to inadequate or unavailable transportation, disability specific limitations, and financial limitations. Distance and lack of access are just two threats to quality of care that now being addressed by the use of videoconferencing, information exchange, and other telecommunication technologies that facilitate telerehabilitation.

This white paper illustrates and summarizes clinical and vocational applications of telerehabilitation. We provide definitions related to the fields of telemedicine, telehealth, and telerehabilitation, and consider the impetus for telerehabilitation. We review the telerehabilitation literature for assistive technology applications; pressure ulcer prevention; virtual reality applications; speech-language pathology applications; seating and wheeled mobility applications; vocational rehabilitation applications; and cost-effectiveness. We then discuss external telerehabilitation influencers, such as the positions of professional organizations. Finally, we summarize clinical and policy issues in a limited context appropriate to the scope of this paper.

Keywords: Telerehabilitation; Telehealth; Telemedicine; Telepractice

Introduction

Telerehabilitation (TR) is the application of telecommunication technology to support rehabilitation services (Russell, 2007). The typical telemedicine encounter involves a short, intensive session between a clinician and a patient. The rehabilitation process, in contrast, requires the continuous and frequent monitoring of the patient's functionality to test the delivered therapy and/or adapt it to the patient's progress. The specific nature of the rehabilitation (e.g., speech-language therapy; audiology; occupational therapy; rehabilitation counseling; physical therapy; assistive technology/ wheelchair evaluation, etc.) will dictate the characteristics of the telecommunication technology and the informatics infrastructure that will best support the service.

TR is experiencing rapid growth and is fast becoming a significant segment of telemedicine and e-health. Telerehabilitation services that were previously too expensive to deliver are now reasonably affordable due to advancements in Internet technologies and the availability of broadband connections in both the home and workplace. Moreover, these technologies are poised to support the development of new paradigms for telerehabilitation delivery and management.

This paper presents a systematic review of the nature of the emerging field of telerehabilitation from the perspective of health information management with an informatics infrastructure, and then reflects upon the conditions required for future growth.

Review of Science: Telerehabilitation Infrastructure

Almost all published work on TR focuses on the clinical application of a technology to deliver a specific rehabilitation service over a distance. We reviewed these clinical applications to discern the current state-of-the-art of the underlying informatics infrastructure of TR services. [It is important to note that a researcher typically first presents their advances in health informatics at a peer-reviewed conference. The professional association publishes an abstract of the presentation within the

conference's proceedings. A full description of the research subsequently enters a peer-reviewed journal, with journal publication sometimes occurring two or more years after the initial conference presentation.]

The field of TR exists under the assumption that the barriers imposed by distance can be minimized, thus enhancing access and introducing new possibilities for delivering intervention strategies across the continuum of care. It is now possible to minimize the barrier of distance via several modes of telecommunications, including voice, video, and virtual reality. Previously, TR was viewed as a field that focuses heavily on real-time interactivity (synchronous interaction) rather than store-and-forward approach (asynchronous interaction) (Winters, 2002). As a result, most studies and developments focused on inventing devices that can mimic face-to-face interactivity in a tele-setting. In addition, it can be difficult to replicate the methodology of a particular study in a real clinical setting due to insufficient resources and limited device availability.

A systematic approach to analyzing TR services is essential to understand the underlying infrastructure requirements to support the service. We will use a conceptual model of TR service delivery developed by Jack Winters (2002) several years ago, that is still relevant today. Winters proposed four conceptual models: teleconsultation, telehomecare, telemonitoring, and teletherapy. We will use this conceptual model to systematically review the current state of the art of telerehabilitation services.

We reviewed papers published in the past two decades in the area of TR. A search was conducted in the Medline (Pubmed) database using the following keywords: telerehabilitation, telemonitoring, telehomecare, teleconsultation, and teletherapy. With the exception of the keyword telerehabilitation, the aforementioned keywords can justifiably be included in papers that contain no TR content. For example, use of the keyword teleconsultation resulted in 2,069 papers retrieved from Pubmed database. To achieve better precision without sacrificing recall, we combined the last four keywords with keyword rehabilitation. The quantity of papers retrieved using those keywords is as follows: telerehabilitation (93 papers), teleconsultation and rehabilitation (129 papers), telehomecare and rehabilitation (5 papers), telemonitoring and rehabilitation (37 papers), teletherapy and rehabilitation (4 papers). Field specific keywords, such as 'teleSLP', 'telePT', 'teleophtalmology', and 'teleneuropsychology' were also used to query the database; however, the search results for these keywords were already included in the broader keywords. We further refined the retrieval process by reviewing the papers' abstracts and including only papers that relate to rehabilitation services. We further evaluated the content of the papers to reclassify the papers into more accurate TR service categories. The result was 238 papers related to TR as per the categories presented in Table 1.

Teleconsultation
Number of papers: 61
Prototypical example: Brennan, Georgeadis, Baron, & Barker, 2004

Telemonitoring
Number of papers: 36
Prototypical example: Piette et al., 2008

Telehomecare
Number of papers: 36
Prototypical example: Hoenig et al., 2006

Teletherapy
Number of papers: 60
Prototypical example: Sugarman, Dayan, Weisel-Eichler, & Tiran, 2006

Telerehabilitation Service: Other
Number of papers: 45

Table 1. Papers (within the past two decades) that included TR services.

TELECONSULTATION

Winters (2002) defined teleconsultation as a standard "face-to-face" telemedicine model using interactive videoconferencing between a local provider (and client) and a remote rehabilitation expert to gain access to specialized expertise. Of the 238 papers we reviewed, 61 were related to teleconsultation. We will use two applications to represent the teleconsultation service delivery model: Assistive Device Teleprescription and Expert Teleaccess.

Assistive Device Teleprescription is a clinical application of teleconsultation wherein clinics located in rural settings expand the availability and expertise of their onsite therapist(s) by interacting with an expert therapist from a metropolitan area. Assistive device teleprescription may be applied to orthoses, wheelchairs, and augmentative communication devices (Lemaire, Necsulescu, & Greene, 2006). In the wheelchair remote prescription system, an expert therapist can join wheelchair assessment and fitting process via a videoconference system.

A second application, Expert Teleaccess, is a teleconsultation service that allows a therapist who practices in a rural setting to access the expertise of a specialized therapist within a clinic or hospital. Iwatsuki, Fujita, Maeno, & Matsuya (2004) described the use of Expert Teleaccess to train physical therapists in rural areas. The process is initiated by transmitting movement pictures of the client to the expert therapist in the

metropolitan hospital. After analyzing the movement pictures, the expert therapist provides inputs on the client's treatment plan. The rural therapist finalizes the treatment plan by combining the expert inputs with the client's preferences.

Telehomecare

Telehomecare service delivery occurs when a clinician (usually a nurse or technician) coordinates a rehabilitation service delivery from various providers to the client's home. We will briefly review three clinical applications that represent the telehomecare service delivery model: In-home Teletraining, Home Modification Teleassessment, and the Telesupport Network.

The In-home Teletraining service delivery model enables a home-based client to learn and practice Activity of Daily Living (ADL) tasks with the guidance of a distant therapist and a home-based technician. Hoenig et al., (2006) described a protocol to deliver in-home teletraining to adults with mobility impairments. The training session employed a camera connected to a standard videophone line. This configuration allowed the distant therapist to monitor the process in real-time, remotely. Feedback from the therapist was transmitted through the audio line. The client-side used a wireless headset to receive the audio feedback; this enabled the client to move freely during the training session.

Home Modification Teleassessment is a clinical application of telehomecare that allows an architect/accessibility expert to evaluate the accessibility of the client's home (Sanford et al., 2006). In this application, technicians visit the client and capture specific images of their home. An architect/accessibility expert remotely uploads and analyzes the images. Kim (Kim & Brienza, 2006) extended the approach further by building 3D models of the clients' homes to allow virtual navigation. Based on the models, the architect/accessibility expert can provide a set of recommendations to make the home more accessible.

Telesupport Network is a clinical application of telehomecare that provides ongoing/lifetime support for the client via a network of healthcare resources. The network provides a web-based care coordination system that enables homecare staff to interact with providers from acute rehabilitation sites. Additionally, the network can provide supplemental information about homecare, rehabilitation, and other education resources. The network was constructed to address specific circumstances that can be problematic to rural clients: medication noncompliance; social isolation and inadequate supervision; limited access to specialty service; and lack of communication between homecare agency and hospital (Demiris, Shigaki, & Schopp, 2005). The network can also connect peers with similar rehabilitation needs (Schopp, Hales, Quetsch, Hauan, & Brown, 2004).

Telemonitoring

Telemonitoring is a clinical application wherein the rehabilitation provider sets up unobtrusive monitoring or assessment technology for the client. Some telemonitoring approaches allow a limited degree of interactivity between the client and the provider via the device. Telemonitoring is perhaps one of the most frequent applications of telerehabilitation, with significant growth potential due to the availability of inexpensive and nonintrusive environmental sensors placed in the home, and the advancement of wireless networks.

One example of telemonitoring is independent-living telemonitoring. Independent-living telemonitoring uses a range of devices, from the simple emergency call button to sophisticated home sensors. The goal of this telemonitoring application is to allow clients to live independently while their health and safety are monitored remotely by health providers.

Another example of telemonitoring is job telecoaching. An automated agent capable of providing instant feedback is coupled with the client as a partner. The device is programmed to identify missing steps or false movements made by the client. By creating a model of the client's movement and comparing the model with the correct movement model stored inside the device, instant feedback is produced to remind the client of the missing or false movement.

Teletherapy

Arguably, teletherapy, the most visible application of TR services, is defined as a model of TR service delivery wherein the client conducts therapeutic activities in the home setting using a therapy protocol that is remotely managed by the therapist. The therapist typically has the ability to modify the therapy setting either synchronously or asynchronously. Three clinical applications are reviewed to represent teletherapy: teleneuro/orthopedic-rehabilitation, teleaudiology/teleSLP, and postsurgical teletraining.

Teleneuro/orthopedic-rehabilitation is the clinical application wherein neural/orthopedic-related rehabilitation therapy is delivered remotely. This clinical application category includes post-stroke TR service, traumatic brain injury (TBI) TR service, and orthopedic TR service. Feng and Winters, (2007) combined an off-the-shelf force feedback joystick with instant messaging and videoconferencing to create computer-based assessment tools for neurorehabilitation. These tools also provide instant evaluations of therapy performances that are integral to the therapeutic process. The computer-based tools and the goals they establish (e.g., game achievements and targets) can help motivate the client to sustain their interest and therapeutic engagement. Moreover, computer based tools can provide digital

metrics with a higher sensitivity to the client's subtle changes (including range of motion and pressure strength) compared to traditional clinical assessment scales. Virtual reality can also be used to provide TR service. Virtual gloves (Placidi, 2007) and haptic devices provide force-feedback, allowing the client to interact with an immersive virtual reality environment in the therapy session.

Teleaudiology/TeleSpeech-Language-Pathology (TeleSLP) is a clinical application that provides speech-language therapy and audiology services at a distance. TeleSLP can utilize both synchronous and asynchronous communication modes. Real-time interaction is employed to identify facial gestures and expressions, while a "store-and-forward" method is used to send numerical data to the therapist. Additionally, video can be stored and forwarded to provide higher-quality video recording without the need for high bandwidth (Hill et al., 2006). By using a store-and forward method, data metrics can be aggregated and analyzed to deliver personalized therapy for the client.

Postsurgical teletraining is the clinical application to deliver remote rehabilitation after a surgical process. Rehabilitation for post surgery interventions concentrates on regaining range-of-motion, strength, and relieving sensitivity in the surgical area (Heuser et al., 2007). Teleneuro/orthopedic-rehabilitation and virtual reality can used to provide remote training for the client. However, postsurgical teletraining generally focuses more on the continuity of self-training and requires less real-time interactivity with the therapist. Data can be uploaded periodically and aggregated in the server for the therapist's review.

TELEREHABILITATION FROM AN INFORMATICS PERSPECTIVE

Defining the relationships between telemedicine and other related areas is important to design an optimal IT infrastructure. In stricter terms, telemedicine is usually defined as the delivery of clinical services. Since TR may involve the delivery of clinical services such as teletherapy, TR intersects with telemedicine. The other TR models fall under telehealthcare or e-health, the term used to refer to the management of disability and health.

The field of telemedicine can be mapped into four quadrants based on the axes of intensity and duration of the clinical service delivery. The intensity is the amount of information exchanged (usually measured by the size of the files used, speed/resolution of the video required, etc.) between the participants in the telemedicine process. The intensity ranges from high intensity (e.g. for tele-surgery) to low intensity (e.g., for in-home rehabilitation). The high intensity services such as telesurgery usually require very high-quality real-time video connection between two sites and a very high speed connection to

allow real-time manipulation of commands or objects on the remote side. Low intensity telemedicine services are delivered by using plain old telephone service (POTS). On the duration axis, the service ranges from short duration service to long term or lifetime service. An example of a short duration service is tele-radiology, which typically consists of one-time diagnosis by a remote radiologist on the images sent by a hospital. An example of long duration service is community integration of persons with disabilities or the management of stroke/SCI recovery.

Figure 1 illustrates many telemedicine services mapped into the intensity-duration axes. Traditional telemedicine such as teleradiology and telepathology mostly falls into the high intensity – short duration quadrant. These types of services require very reliable high-speed connections between two sides. These services usually involve a short, one-time encounter that either does not repeat or only repeats a few times. Telerehabilitation services are mostly in the low intensity – long duration quadrant. For example, rehabilitative retraining after surgery usually involves low intensity monitoring and course of therapy by healthcare providers. TR services, however, usually require repetitive encounters over long time spans.

The quadrant model is used to analyze the service delivery, not the mode of data transmission (store-forward or synchronous) nor the data transmission speed. Intuitively, low-intensity services are delivered via low-speed connections such as the POTS (Plain Old Telephone System), although low-intensity services are increasingly delivered via high-speed connections to achieve better quality of service. The unavailability of high-speed connections required for high-intensity services is often circumvented with the store-forward method of delivery for services that do not require live communication. Teleradiology is an example of a high-intensity service that does not require synchronous communication and often can be conducted via the store and forward method.
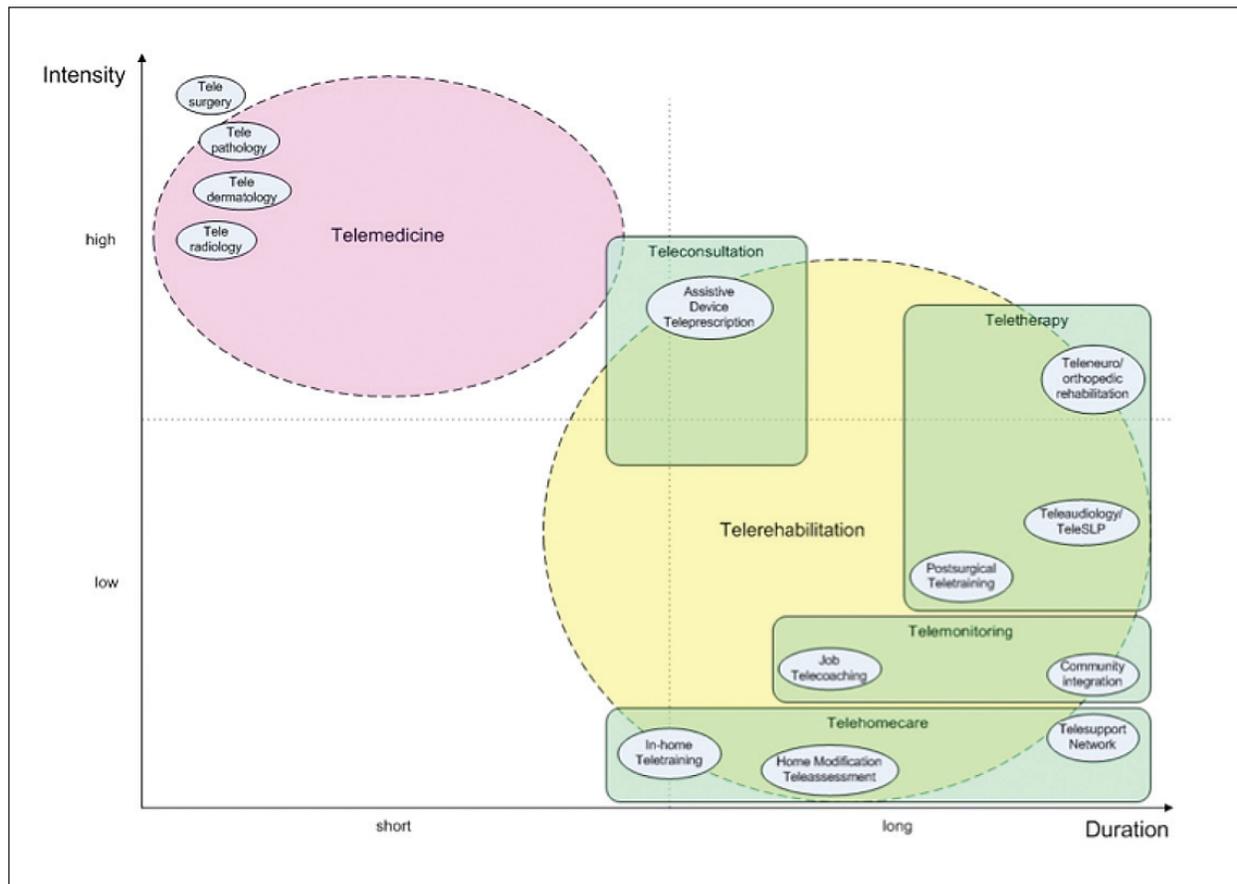
*Figure 1. Map of telemedicine services in the Intensity-
Duration Quadrant Model*
*This figure shows the four quadrants of possible telemedicine
applications. These range from a short duration process with
low intensity to a long duration process with high intensity.
Most TR services are of long duration with a relatively low
intensity, while other telemedicine applications such as
telesurgery and teleradiology fall into the short duration -
high intensity quadrant.*

Chronic disease management involves monitoring over
a long time period. The interaction and communication
in chronic disease management usually is of low
intensity. Therefore, chronic disease management using
telemedicine can be categorized into the low intensity –
long duration quadrant. Chronic disease management
shares many features with telerehabilitation. In contrast,
traditional telemedicine shares the characteristic of acute
disease management: intense, but of short duration.
Because TR services require continuous therapy over a
long time span, there are implications for the informatics
support of telerehabilitation. Informatics requirements
for telerehabilitation services include maintaining the
longitudinal health record and supporting the course of
treatment.

There is a dynamic interaction between infrastructure
and services in TR: the availability of infrastructure affords
new services and the need for services can stimulate
the development of new infrastructure. Developing a
conceptual model of TR services is important since unlike
telemedicine, TR is an emerging field and is much more
diverse. This model will allow us to define the difference
and the relationships between TR, telemedicine,
telehealth, e-health, etc. From the information technology
(IT) standpoint, a systematic review of the advances in IT
is important to understand the optimal IT infrastructure for
TR and to project what TR services might look like in the
future.

The service deliveries in each of the four quadrants
demand different types of IT infrastructure and
bandwidth requirements. A typical infrastructure for
a teleconsultation is videoconferencing over a high-
bandwidth network, while telehomecare typically requires
only low to moderate bandwidth. Telemonitoring and
teletherapy usually require moderate to high bandwidth.
We can identify the IT infrastructure requirements for the
four models of service based on the Intensity-Duration
Quadrant model of TR.

The telemedicine quadrant model can be used to analyze many telemedicine scenarios. For example, the quadrant model can analyze similarities between telemedicine services to determine when and how certain technologies might be used across different telemedicine services. The quadrant model can also help explain why certain TR services that were developed in research contexts are difficult to deploy in real life settings. For example, the telecoaching service is difficult to implement because it is high-intensity, high-bandwidth service.

Low Intensity – Long Duration (LI-LD) Quadrant

Most TR services fall into the low intensity – long duration quadrant. The services in this quadrant are characterized by low-intensity interactions between the client and healthcare provider/therapist, but are conducted over a long time span. Telehomecare and telemonitoring are two typical TR service delivery models that fit into this quadrant. Services with low-intensity interactions do not require high-bandwidth and can be delivered directly to clients at home.

The requirement for this quadrant is an infrastructure that allows retention of rehabilitation data over long time period on a low to medium bandwidth connection (common household connection).

Asynchronous IT infrastructure is used by significant number of rehabilitation service delivery sites in the low intensity – long duration quadrant. Asynchronous communication stores and forwards rehabilitation data to the therapist; this allows data retention over long time periods. In the asynchronous communication models that were used in the past for at-home TR projects, large data files were transmitted in small chunks over low to medium bandwidth channels, allowing the infrastructure to be deployed over common household connections.

A wide array of devices are used to capture data at the client's side in the low intensity – long duration quadrant, ranging from simple emergency call button to automated monitoring robots. Therefore, the asynchronous IT infrastructure also requires a network that supports multimodal data and can be interfaced easily with the devices. Almost all networks can support asynchronous communication. POTS, wireless networks, and the Internet are great candidates to deploy the asynchronous IT infrastructure. POTS has the advantage of availability and simplicity. Wireless networks can be accessed from anywhere, and have the advantage of accessibility. The Internet has the advantage of multimodal sophistication and access to web-based health resources.

High Intensity – Short Duration (HI-SD) Quadrant

The services in this quadrant are characterized by a very intensive interaction between client and provider conducted over a short time period. From the information flow perspective, information flows in a burst. In essence, the TR services in this quadrant are similar to the traditional telemedicine services. We identified one service delivery model that falls into this quadrant: intensive teleconsultation. Most of the services in this quadrant are conducted in clinical settings and connect rural and metropolitan area clinics. Therefore, the requirement for this quadrant is an infrastructure that allows high intensity, interactive communication over a short time period. Due to the setting, the bandwidth needed can range from a medium to high-speed connection.

Synchronous IT infrastructure fits with the requirements of the HI-SD quadrant. High-quality videoconference systems combined with interaction tools are necessary to allow an effective communication in a teleconsultation. The level of interaction needed varies between clinical applications. Assistive device teleprescription generally requires a high level of interactivity such as high-quality videoconferencing, which allows a real-time assessment of the client remotely. On the other hand, depending on the field, expert teleaccess can be built over an infrastructure with less level of interactivity.

High quality video and audio systems are a necessity for the HI-SD quadrant. The video/audio systems are utilized to show detailed aspects either of the client or the therapy materials. Additionally, the video/audio systems are also used as communication tools allowing feedback from the therapist to be delivered in a timely manner. Therefore, a very high-speed and reliable network is required for the IT infrastructure to support services in this quadrant. A dedicated network (ATM, ISDN) and the Internet are great candidates for the IT infrastructure in this quadrant. A dedicated network has the advantages of being reliable and able to support all types of communication. The main disadvantages of a dedicated network are the cost of the device and the network, and the proprietary nature of the technology. The Internet has the advantage of lower cost and an open system that can be easily integrated with other components of the IT infrastructure. Finally, the reliability and security issues associated with Internet deployment should be addressed with extra precautions.

HIGH INTENSITY - LONG DURATION (HI-LD) QUADRANT

The services in this quadrant are characterized by an intense interaction between the client and the healthcare provider/therapist. Though each individual session is generally short, the service consists of many sessions conducted over a long period of time. We identified one service delivery model for this quadrant: Teletherapy. The settings for TR services for the High Intensity - Long Duration (HI-LD) Quadrant can vary from client's home to a clinical setting. Most TR services in the High Intensity - Long Duration (HI-LD) Quadrant use both modes of communication. Therefore, the requirements for this quadrant vary based upon the type of the therapy. Therapies that rely on videoconferences generally need a high intensity infrastructure with medium to high bandwidth, while therapies relying on store-and-forward approach can often make use of a low intensity infrastructure with medium to low bandwidth.

A flexible computer network that allows for an integration of systems is necessary to support the High Intensity - Long Duration (HI-LD) Quadrant as most of the services utilize both mode of communication. A network with the capability of integrating synchronous and asynchronous application is required to implement the High Intensity - Long Duration (HI-LD) Quadrant infrastructure. The Internet becomes a great candidate to deploy the High Intensity - Long Duration (HI-LD) Quadrant. Although it requires certain measures to ensure reliability and security, the Internet has the advantage of flexibility and scalability, and allows for the seamless integration of modules in a computer-based solution.

EMERGING ISSUES AND CHALLENGES

As telerehabilitation and homecare become popular due to the availability of the technologies and the economic potential of reducing the cost of services, TR can potentially increase access to care. Greater access to care is becoming   increasingly important in light of a clinician shortage and an aging population. TR also brings emerging issues and challenges that will need to be recognized and addressed. We will review three notable challenges: the management of complex health information, privacy/confidentiality issues, and the need to design a consumer-centered system.

COMPLEX HEALTH INFORMATION

Rehabilitation service is characterized by repetitive encounters over a long time period. In some cases, a video stream is recorded for every encounter. This type of information is not recorded in a face-to-face rehabilitation session. For example, during a neuropsychological session, only assessment is recorded, not the entire session. During a face-to-face wheelchair prescription session, no recording is made of the session between ATP and the prospective wheelchair user. In TR however, the entire session, including the details of activities, are captured by the video system that link the therapist with the remote patient.

Since TR encounters are repetitive over long periods of time, the information accumulated from every encounter needs to be stored and organized to allow therapist to easily view the information. Managing a wealth of information in a complex form (such as video, sound, text, and still images) poses a new challenge in TR. The ability to determine which information is most important will underlie the future success of TR. The field of visualization and human-computer interface will be very useful to solve these challenges.

The recording of entire sessions might also bring opportunities that previously did not exist. Videos of the interactions between therapists and patients can be used to educate future therapists. Presently, students depend heavily upon shadowing therapists to learn how to conduct clinical sessions. Video recorded TR sessions can constitute a educational repository to enhance and supplement clinical education. There is also the potential to apply the field of data mining to learn and characterize the wealth of data was that previously not available.

PRIVACY/CONFIDENTIALITY ISSUES

Imagine that a video of a TR psychological therapy session is stolen and posted on the Internet, or forwarded to the wrong person. This scenario would be very damaging to the patient and to the credibility of the TR services. TR services thus bring more challenges to privacy and confidentiality than face-to-face rehabilitation, as the latter leaves no trail beyond the therapy room. In the future, it will be common for entire sessions of rehabilitation therapy to be either recorded or captured over the Internet. While the availability of a digital version of the details of a therapy session can potentially create opportunities for research and education, this can also present challenges in terms of privacy/confidentiality and liability. As all medical fields begin to adopt electronic medical records, consumers will gradually become more comfortable with technology-enabled healthcare. However, it is important to develop TR systems in such a way that their users feel as comfortable and secure as they do when seeing a clinician in person.

CONSUMER-CENTERED TELEREHABILITATION SERVICES

The convergence of TR services with the Internet will bring TR services closer to the consumer. Unlike telemedicine of the past, the users of future TR system will be the public, rather than healthcare professionals. That is, clients will independently use the system to access the course of treatment or to record data. This will bring new challenges to the design and development of TR infrastructure. Unlike healthcare professionals, public users may be more dynamic, moving from one healthcare system to another according to their needs and personal preferences. Therefore, a client's data must be able to follow the individual. The need for health data to follow the individual will force different systems to interface with one other. Client data and information will have to flow from one system to another to ensure the integrity and the completeness of the client's health record.

EMERGING TECHNOLOGIES AND OPPORTUNITIES

As in the case for other industries, future advancements in Internet technologies will provide opportunities to change the landscape of TR services. Notable advancements that could function as significant agents of change include: the availability of very high-bandwidth in most household and offices; the advent of Web 2.0 technologies that can bring integration to TR services; and the push toward consumer empowerment and personal health information. These forces will shape the development of the landscape of the telerehabilitation services and infrastructure in the next decade.

The advent of Web 2.0 provides potential technologies to build a platform to deliver TR service. Via the use of these technologies, multiple information and collaboration features can be integrated into a single application built on top of the Internet. In addition, the increasing availability of bandwidth allows heavy, high-bandwidth applications to be developed and delivered through the Internet. With the high rate of internet penetration in rural areas, building the application over the Internet also increases the accessibility of the solution to both metropolitan and rural areas.

Following this advancement, there is a growing trend for all the branches of telehealth (telemedicine, telehealthcare, and e-health) to be integrated into a single mode of service. The concept of providing a "single-entry" to the system that supports the service is viewed as an efficient way to provide complete information about a client to healthcare providers. The current sophistication of Internet services and the speed of networks will allow opportunities for integration that were not possible during the past decade. For example, real-time videoconferencing can be integrated with the clinical information system or other information management systems, allowing healthcare providers to get real-time feedback on the client's condition while assessing and performing decision making on the client's therapy.

THE AVAILABILITY OF HIGH-BANDWIDTH, HIGH-DEFINITION TECHNOLOGIES

By the end of 2006, the penetration of broadband connections among Internet users in the United States was estimated to reach 80%, while more than 90% of US workers used broadband (Madden, 2006). Extrapolating the current trend, as the broadband penetration between Internet users is almost universal, the category for future bandwidth may no longer be between broadband (56Kbit or higher) and regular telephone lines (56 Kbps or less), but between many forms of broadband. Already, the current speed of broadband access in the US is 384 Kbps or higher, with Cable providing connections with a speed between 384 Kbps - 1.5 Mbps (both downstream and upstream) and Digital Subscriber Line (DSL) providing a speed between 768 Kbps -5 Mbps (downstream) and 384-768 Kbps (upstream). New DSL technology on top of fiber optics (e.g. Verizon FiOS) connection can provide a speed between 5-15 Mbps (downstream) and 2-15 Mbps (upstream).

The availability of high-bandwidth infrastructure provides a channel to transmit various types of data between TR sites. In addition, advancements in haptic controls and personal monitoring devices allow for higher quality client data to be gathered. With proper optimization, these data can be efficiently transferred through the high-bandwidth infrastructure, thereby providing more complete information about the client during the therapeutic assessment.

The increase in high bandwidth availability also drives most video conference developers to incorporate high-definition (HD) content into their systems, allowing higher quality of multimedia files to be transmitted over the network. Although the use of HD content in TR is currently limited, this technology has the potential of increasing the quality of TR assessment, especially in assessments that rely on visual cues and information.

TELEREHABILITATION AND THE INTERNET

Prior to the mid-1990's, the unavailability of high-speed and reliable connections over the Internet forced telemedicine and telerehabilitation services that required video to be delivered over proprietary systems and ISDN lines. The result was a proprietary environment with little potential for integration of informatics support across workflow. For example, videoconferencing was usually a

separate service, while database or health records were supported by a different system. The Internet gradually became suitable as a platform for demanding interactive services, such as videoconferencing, due to the advancement of broadband speeds. The drawbacks of the Internet in the past (e.g. potentially higher packet loss and low quality of service) have become less of a factor as the speed and quality of the Internet increased. Currently, most developers of videoconferencing systems have adopted the concept of communication over IP in addition to the traditional ISDN channel. Since their introduction in the mid-1990's, the percentage of video calls hosted over IP networks has continued to grow, and it is estimated that IP networks will become the most common network used for hosting videoconferences in 2008 (Wainhouse Research, 2006).

The future of the TR infrastructure points toward multimodal services delivered over multimodal telecommunication applications. The Internet has tremendous potential as the standard platform for future multimodal telecommunications. An integrated TR service that includes teleconsultation,　　e-health, and teletherapy can be delivered using multimodal applications (e.g., videoconferencing, personal health record access, personalized consumer health information, remote monitoring, etc.) over a single communication channel. The massive investment on the collaboration software by the computer industry will also provide a boost to this convergence.

The Internet's advantage over other networks includes ease of access, expandability, scalability, and low expense. The advent of the Web 2.0 technologies characterized by advanced networking and collaborations, as well as technology for service delivery, render the Internet more attractive as a platform for TR applications. Deploying Web 2.0 technologies on top of the Internet will allow for the development of sophisticated applications that integrate videoconferencing, stimuli presentation, electronic medical record, online collaboration, and other services into a single multimodal system. Employing this approach and open-source technologies will enable the rapid development of an integrated multimodal TR service in a low cost fashion.

Towards Evidence-based Telerehabilitation Services

To ensure the flow of data, a standardized data exchange protocol for TR must be established. Following the telemedicine trend, we believe it is imperative for the TR field to create a standardized protocol to ensure the continuity of care for the client across any rehabilitation providers. This area is still in infancy both in terms of research and in the development of informatics infrastructure. Some preliminary work in this area has started to emerge. For example, Demiris (Demiris,

Shigaki, & Schopp, 2005) identified the set of clinical data to assess the impact of clinical applications to include:
- Patient demographic information
- Outcome and Assessment Information Set (OASIS) data set
- Short Form (SF)-36 Health Survey data set
- Functional Independence Measure (FIM)
- Data on hospitalizations, emergency room, and medical office visits
- Geriatric Depression Scale (GDS) for older adults population
- Secondary Conditions Questionnaire, an instrument designed to assess secondary conditions for person with rehabilitation conditions

Providing complete information about a client will enable them to track their therapeutic progress and potentially increase their motivation. Complete information will also help the therapist make informed decisions and customize the client's therapy.

Summary of Findings

TR offers opportunities to provide equitable access to advanced rehabilitation services that would not otherwise be available to underserved populations in both rural and urban settings. TR also has the potential to allow small community clinics to expand their services to include specialized services. In light of an aging population and a healthcare provider shortage, TR will play a greater role in delivering rehabilitation services to reach more individuals in both rural and metropolitan areas.

The keys to providing TR infrastructure are affordability, reachability, and scalability. The Internet has the potential to become the backbone for TR because it supports TR developments that are cost-effective, can reach most computers and mobile devices, and are scalable worldwide. The Internet has attractive features for developers in that it is open, highly scalable, capable of handling multiple types of data, and flexible to customization. The trend toward portable monitoring devices and smart-home technologies also provides TR with new opportunities to bring specialized services closer to the clients.

These potential benefits will not be realized until TR systems can be easily adopted by healthcare service providers and clients. Since usability is a key factor in technology adoption, the development of a usable IT infrastructure to support TR will be crucial for clinical and consumer acceptance. The conduct and use of evidence-based TR studies will also be important to promote the benefits of TR in limited condition settings.

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This document is a draft intended for use by

participants in the Rehabilitation Engineering

Research Center on Telerehabilitation's State of

the Science Conference to be held November

17-20, 2008. The document may not be distributed

and should be discarded after the conference.

A final draft will be developed in response to the

discussions taking place during the conference.

The paper will be published in final form in the

April 2009 issue of the International Journal of

Telerehabilitation. We look forward to your active

participation in the conference and welcome any

comments you have related to the information

presented here.