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Low-bandwidth telemedicine for remote orthotic assessment

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Abstract

A model for performing remote orthotic assessments using low-bandwidth computer communication technology (video conferencing) was developed, tested, and evaluated. System evaluation involved comparing a series of remote assessments with on-site assessments. While most on-site and on-line results were similar, discrepancies which occurred were attributed to between-clinician differences, measurement technique differences, technical and learning obstacles at the start of the project, and within subject variations during the day. On-line assessment efficiency improved with each on-line session and corresponded with increased confidence in the system, easier system use, and better overall satisfaction. An on-line debriefing session was held with all project clinicians. These clinicians supported continued use of the communication system for rehabilitation consultation and education. Clinically, preliminary face-to-face meetings and a regular practice schedule were recommended. Technically, the system was considered good; however, suggested improvements included using a high quality speaker-phone system, streamlining the video capture process, and providing more reliable telecommunication connections.

Introduction

The combination of computer technology and telecommunications is an exciting prospect for the rehabilitation field. Recent advancements in video conferencing systems and Internet access provide the infrastructure for remote assessment and consultation at a reasonable cost. By using computer/telecommunication links to send sound, data, graphics, and video between two or more sites, remote areas can access clinical assessment and follow-up services without travelling to a central rehabilitation facility.

Telemedicine, the use of communication technologies to provide health care services and education over a distance, has been in existence since the late 1950s when microwave links were used for telepsychiatry consultations (Wittson *et al.*, 1961). Since then many applications have been initiated in the fields of radiology (Reponen *et al.*, 1995; von Hanwehr *et al.*, 1995) dermatology (Perednia and Brown, 1995; Solomon *et al.*, 1996), pathology (Ferrer-Roca *et al.*, 1995; Kayser and Drlicek, 1992), neurology (Chaves-Carballo, 1992), and other specialties (Allen and Hayes, 1994; Hubble *et al.*, 1993; Jerome, 1993; Rafuse, 1994; Lewis and Boyd Moir, 1995). In addition, some telemedicine initiatives have provided remote diagnosis and consultation tools for general health care (Carlson, 1994; Jennett *et al.*, 1995; Perednia and Allen, 1995; Padeken *et al.*, 1995; Sanders and Tedesco, 1993). Unfortunately, most of these programmes could not be sustained after the initial project funding was spent (Perednia and Allen, 1995).

The technological requirements for performing a remote medical intervention are directly related to the clinical application. For radiology and pathology, static images can be digitized at a remote site using commercial image processing hardware and software. A computer modem can then be used to send the data file to a central facility for analysis (Reponen *et al.*, 1995). For surgical interventions, virtual reality or

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telepresence is required so that the surgeon has sufficient visual and tactile feedback to perform an operation. Such a system might include a high speed telecommunication link, remote robotic controlled surgical instruments, three-dimensional (3D) video display, high quality audio, and computer-enhanced instruments that allow the surgeon to feel what the remote surgical instrument is doing - all functioning in real-time (Dumay, 1995; Ling, 1993; Satava, 1995[a,b]). While remote rehabilitation consultations would benefit from a full virtual reality interface, a more reasonable approach can be taken to provide reliable clinical interventions and education sessions (Ball 1994; Lemaire, 1993; Lemaire *et al.*, 1997). Simple, but effective, telemedicine implementations have generally had the most success (Pushkin, 1992).

While the benefits of on-line communication are well documented (McNamara, 1994; Williams *et al.*, 1995), little research has been published concerning the application of this technology to physical rehabilitation. Until recently, the high cost and inadequate capabilities of computer communication hardware and software made rehabilitation telemedicine inaccessible; however, recent developments have reduced the cost of distance communication systems to a level that is compatible with the budgets of most medical clinics. Also, the proliferation of Internet service providers makes the task of connecting remote sites to rehabilitation centres easier and more cost-effective (Bergman, 1994). This document will describe outcome results from using a low cost, low-bandwidth distance communication solution for orthotic assessment.

Methods

The procedures used to develop and validate a distance communication system for remote orthotic assessment are outlined. These involved defining key clinical and technical parameters, installing and pre-testing the communication system, and evaluating the new assessment process.

One central rehabilitation site (The Rehabilitation Centre, Ottawa) and two remote sites (Arnprior and District Memorial Hospital, Hawkesbury General Hospital) were involved with this study. All interactions between the remote communities and the Rehabilitation Centre occurred through the Terry Fox Mobile Clinic (Wilson *et al.*, 1995; Greene, 1993). The Mobile Clinic is an interdisciplinary rehabilitation team that travels to communities in eastern and northern Ontario, Canada. Two certified orthotists from The Rehabilitation Centre completed all orthotic assessments. Four physiotherapists and one occupational therapist from the remote hospitals worked with a central orthotist to complete all on-line assessments.

A total of 22 people who required an ankle-foot-orthosis (AFO) were recruited to participate in this study. These subjects lived in the regions serviced by the remote hospitals and had been previously seen by the Mobile Clinic staff. Ten additional people were recruited from The Rehabilitation Centre for on-site training and testing of the assessment protocol. Informed consent was obtained from all participants before initiating the assessments.

To determine the methods and procedures for orthotic assessment, an inventory of current orthotic assessment practices on the Mobile Clinic was amassed. This information was collected through interviews with Mobile clinic certified orthotists and other members of the Mobile Clinic team. The assessment information was combined with existing forms (Sarrafian, 1985; Berger *et al.*, 1981; England *et al.*, 1977; McCollough *et al.*, 1970; Weber, 1990) to develop a standard assessment form and database for use in this study.

Once the assessment method was defined, two certified orthotists were trained to use this protocol. A group of five lower limb orthotic users was assessed through the Prosthetics and Orthotics Service at The Rehabilitation Centre to ensure that both orthotists were employing the same technique. Both orthotists independently assessed each user and recorded the results on the assessment form. Data are collected from a second group of five subjects to help describe the differences that can be expected due to inter-clinician variability.

After a thorough description of orthotic clinical assessment method was documented, the assessment protocol was adapted to accommodate a computer conferencing link. These adaptations included developing a computer database version of the assessment form and determining how to use the communication tools to obtain the assessment information. The computer hardware and software components were assembled at this time.

When the computer hardware and software were functioning, clinical staff at the Rehabilitation Centre and the two remote sites received training on the computer communication system. The first training sessions were done at the remote sites. Subsequent training sessions were performed using the conferencing link and on-line tutorials (i.e., instructor at the central site and participants at the rural sites).

Following the training, four people were assessed using the distance communication protocol during the first-on-site visit to Arnprior. These tests ensured that the computer assessment methods were appropriate for people who require lower limb orthoses. These pre-tests also permitted debugging of the computer link and gave the participants some experience using the system with users before data collection began.

All test subjects were assessed by an on-site orthotist and by the remote orthotist/local therapist team (using the computer communication link). Both assessments were completed on the same day. Both orthotists used the established assessment protocol and recorded the results on an assessment form.

A computer assessment questionnaire was completed by the on-line orthotist for each assessment. These questionnaires described the time requirements for on-line assessments, factors related to system function, and satisfaction with the system/process.

In addition to the questionnaires, each subject was video taped in the sagittal and frontal planes while walking. Three to five representative strides were selected from the tape, digitized into the computer, and sent to the central orthotist over the communication link for visual gait analysis. The orthotist could replay the digital video clip as many times as required, step through the video frame by frame, and pause the video at any point. The on-site orthotist did not have access to the tape because video analysis was not part of the standard on-site assessment.

Upon completion of the user data collection phase, a debriefing session was held on-line with each community and The Rehabilitation Centre. A preset series of questions concerning the benefits, contraindications, and future developments of the distance communication system were discussed by the participating clinicians.

Using an Internet connection, all three hospitals shared an interactive Chalkboard and Chat window. The Chat feature was used to record all the ideas that came up during the meeting so that all sites could follow, comment on, or add to the written record. A conference call was used for verbal communication. Although the Chalkboard was available, it was only required at the start of the session.

All the data were analysed using descriptive statistics. A Spearman correlation coefficient was used to assess the linearity between ordinal data from the two assessments. The differences between the on-line and on-site assessments should be comparable to the differences when both orthotists completed an on-site assessment.

Hardware/software solutions

IBM's Person to Person (P2P) video conferencing system, running under OS/2 Warp 3.0, was used for this study. P2P provided an interactive chalkboard, chat mode communication, window mirroring, and file transfer capabilities as part of the OS/2 Warp Bonus pack (i.e., software bundled with the operating system). With the addition of a video capture card, P2P could send video and high resolution still images between sites. Audio communication was through a separate telephone line connected to a speaker phone. The OS/2 Bonus Pack also provided a word processor/spreadsheet/database programme and Internet related software.

System setup

IBM hardware was used for this project, although any IBM compatible system could have been used. A Pentium 90 (host site) and two Pentium 75 (remote sites) based systems were used for most of this study. An 80486DX-66 computer was employed for initial system and communication tests. All computers were equipped with 16Mb RAM and a 17-inch monitor. The 17 inch monitor was beneficial since the additional screen space permitted many windows to be open and visible simultaneously (i.e. video window, Chalkboard, database, etc.). System setup and configuration were performed by the research team.

Setting up a P2P session that incorporated live video took much longer than initially planned (approximately three months). Most of the problems were related to faulty device drivers and hardware conflicts. The lengthy system configuration time would be a problem for small

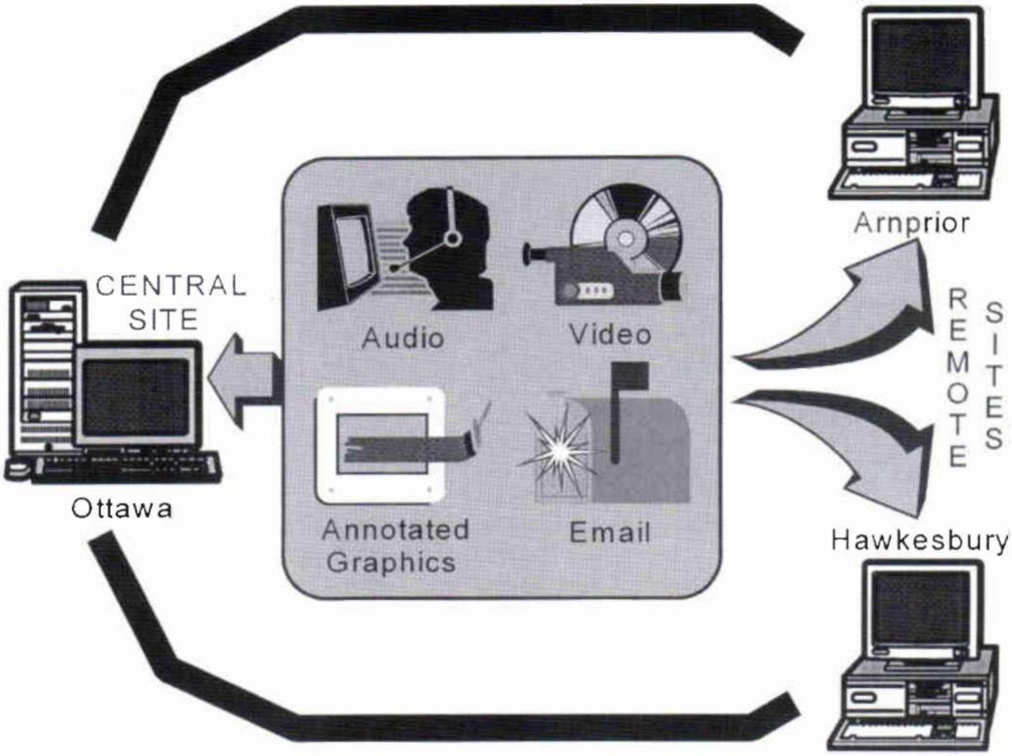

Fig. 1. Computer communication system

health care centres with little computer experience or unavailable computer research personnel. Having the system completely pre-installed and configured for the specific application is essential to build consumer confidence, reduce frustrations, and reduce expensive remote servicing costs.

Communication tools

Video

A live video signal was sent between sites over standard telephone lines (28.8 Kbps) at approximately one frame/second. While this frame rate was too slow for human motion assessment, it allowed both sites to see each other, show an assistive device, or show a problem area on a patient. Since this project focussed on remote communities with limited financial/technical resources and no access to high-speed data lines, the feasibility of standard telephone communications for digital clinical assessment was addressed, as opposed to high-speed ATM networks or satellite links. Since full screen, 20 frames/second video is appropriate for analysing slow walking, a secondary process was initiated to share full speed video data.

Video motion analysis

An essential part of an orthotic assessment is the visual evaluation of a person's walking style. This information is used to help define the problem, determine the best orthotic intervention, and evaluate orthotic function.

An IBM ActionMedia video capture board was used to digitize video approximately 20 fps and save the data on the hard disk (file size approximately 10 Mb). The resulting data file was sent to the central orthotist using the file transfer function. Internet E-mail could also have been used to send the video file to the rehabilitation centre. Software that came with the capture card was used to record, play, pause, and step through the video frame by frame.

Drawing

P2P's Chalkboard could be considered the most important visual communication feature for remote assessment. Any image that is displayed on the Chalkboard can be seen and annotated by all "on-line participants". By displaying and annotating images of an orthosis, walking characteristics, or educational materials, all people connected to the communication system can discuss a problem while seeing and drawing on related images. Since any other programme can be "mirrored" into the Chalkboard (i.e., the contents of the programme's windows are automatically displayed in the Chalkboard as a bitmap), the common viewing area could be used to solve software problems, look at CAD images, or work on reports and documentation. Previous work with the Chalkboard method of remote communication demonstrated the usefulness of this medium, as long as the proper visual material is used (Lemaire, 1993).

Image capture

The image capture function obtained a stationary, 640x480 image from a camcorder and displayed the image in a separate window.

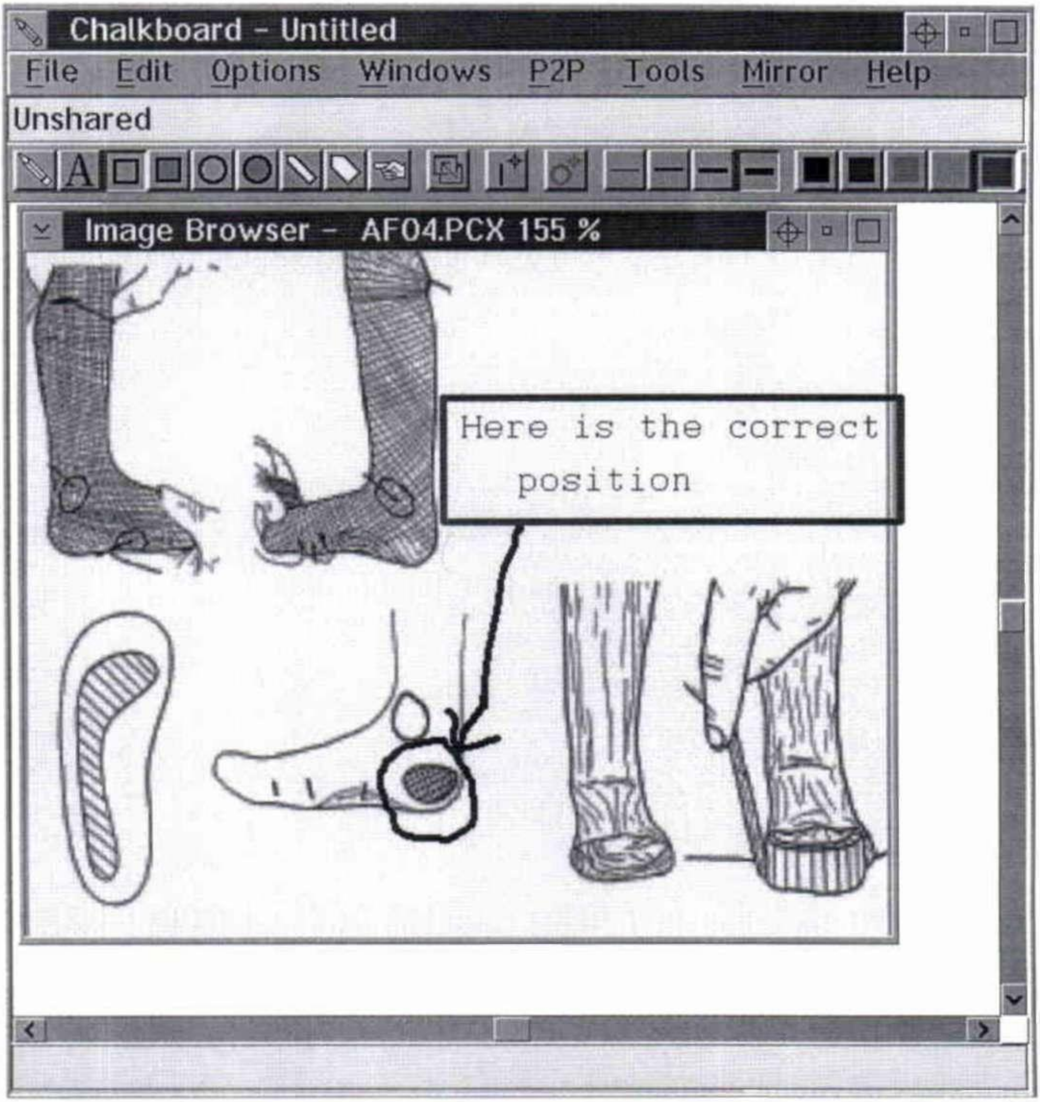

Fig. 2. AFO database – design section

This image could be transferred to the Chalkboard for discussion. Capturing and displaying a large, full colour image allowed the orthotist to see limb redness, chaffing, and the orthosis condition.

Database

An orthotic database programme was initially set up using the IBM Works Datafiler application; however, software problems lead to rewriting the database in Microsoft (MS) Access for Windows 3.1. When the programme errors are corrected, Datafiler should be adequate for maintaining an on-line database for distance communication. The advantage of the Datafiler application is that it is included with the operating system at no extra cost.

A runtime version of the MS Access programme ran in a MS Windows session under OS/2. Database records were shared between sites by copying the record(s), saving these records as a separate data file, sending the data file to the other site using the communication link, and importing the data into the host database. In cases where the data did not have to be transferred to the other site, the database window was mirrored into the Chalkboard for discussion.

Reference images

Before the first on-line session, a series of reference images were scanned and saved as bitmap graphic files. These images were grouped in Light Table folders for easy access (an OS/2 feature for organizing multimedia files by displaying the information as a series of small slides). Since a Light Table was used for image organization, the user can easily share pictures by clicking on the images slide to display a full size picture and mirroring the enlarged picture into the chalkboard. The reference images were very useful for the training sessions and during on-line discussions regarding patient or orthosis characteristics.

Direct modem connection/Internet

For most of this study, direct modem connections were used for communication. While the Internet can be used for remote communication, data transfer can be slow during periods of high Internet traffic. A direct 28.8 Kbps modem connection between two sites was the best medium for communications over a telephone line.

While telephone line data connections were satisfactory, connections between sites were not always reliable. The main connection problems

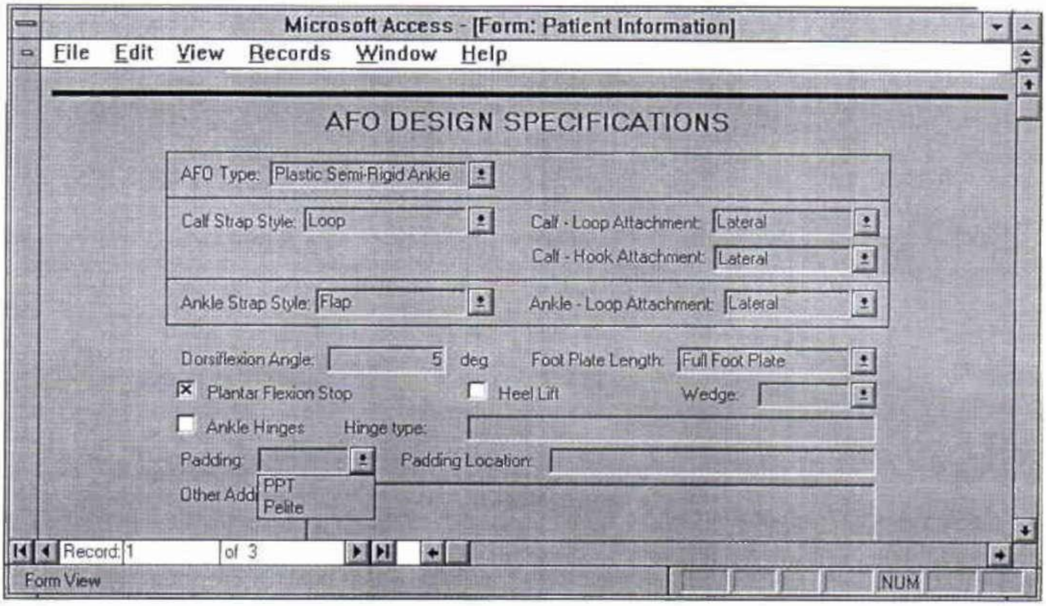

Fig. 3. Reference images

were based on running the system through hospital switch boards. In particular, The Rehabilitation Centre's PBX-based telephone system created data communication problems during the initial stages of this project. Switching to a direct, outside telephone line solved most of these problems. Hawkesbury had more reliable data communications than Arnprior. This could be due to better telecommunication links between Ottawa and Hawkesbury or interference from the Arnprior District and Memorial Hospital switchboard system (the telephone line was routed through the main switchboard).

As small communities with inferior telecommunication links are connected to a clinical consultation system, data line failures can be expected. Generally, this is not a problem since it is a simple task to reconnect and resume the assessment. Frequent connection problems, however, are detrimental to the efficiency of remote clinical communication and user confidence. It is recommended that the telephone system by pre-tested before installing a computer distance communication system to ensure a reliable data flow between sites.

Internet connections were easy to initiate and the connections were reliable. For site-to-site communication, the Chalkboard and live-video functions worked; however, the video frame rate was slower than with a direct 28.8 Kbps modem and a longer time lag occurred between the live action and remote video display. Even with these limitations, an Internet connection was considered a viable medium for cost-effective site-to-site communication.

Multi-site Internet communications involved Ottawa, Arnprior, and Hawkesbury simultaneously sharing the same Chalkboard and Talk window. This feature performed very well when each location took turns accessing the shared resources; however, if all sites continuously used the on-screen pointer function for more than a few minutes the system would lock up (i.e., a continuous data stream from all participants using the Chalkboard). No errors occurred if the participants interacted with short to medium bursts of activity. Live-video was not reliable for multi-site Internet connections. Higher bandwidth TCP-IP connections would be required before live-video could be used between more than two sites. A recommended multi-site setup would involve:

- using the Talk window to keep minutes of a meeting, display/paste text for the group to read, or write words which were difficult to spell;
- using the Chalkboard window to share captured images, previously prepared graphics, or as a sketchpad to illustrate an idea;
- using the Stills Capture programme to grab video images and share them with the group (these images can take between one and two minutes to be displayed at all sites, depending on Internet traffic);
- using the File Transfer programme to send video files, database records, word processed files, or reports between sites.

Results

Twenty-two subjects were assessed during four Mobile Clinic visits: 10 assessments in Arnprior and 12 in Hawkesbury. The first Mobile Clinic visit was used as a test session and was not included in the validation results. With these four subjects removed, data from a total of 18 subjects were used for the evaluation. At the start of the project, clinicians in Arnprior and Hawkesbury had minimal, or no, computer experience and no previous exposure to OS/2. The combination of clinician training on the system, system trouble shooting, and database errors made data from the first clinic visit unreliable. The following sections will describe the questionnaire and debriefing results.

Assessment questionnaire results

The assessment data sheet was divided into three areas: client data, physical data, and gait data.

Client data

The client data section provided information on the client's medical status, social factors, and environmental factors. Orthotic assessment questionnaires have traditionally provided a space to write a description based on patient assessments, discussions, and a medical chart review. To compare these clinical data, the information was coded into three groups: same information (1), same information with some additional details (2), different information (3). Since it is expected that different clinicians will have slight variations in what information they decide is most relevant, group one and group two results were acceptable.

For most measures, the remote and on-site responses were similar in more than 88 percent of the cases. These measures included date of birth, height, weight, gender, diagnosis, date of onset, main problem, occupation, activities, social factors, cognitive status, mobility aids, walking distance, and footware. Four areas with unsatisfactory results were prescription (72%), history (61%), goals (72%) and complications (39%). It was reasonable that differences occurred with prescription and goals since the subjects, while being potential candidates for an AFO, were not being assessed to receive a device from an established prescription (i.e., they were at the clinic to take part in the pilot project and not for a specific orthotic problem). If a written prescription was available for each subject, the prescription results would have been much better since the team would have had specific clinical goals.

Differences in medical history and possible complications were attributed to differences between orthotic methods and physiotherapy / occupational therapy methods. The various fields of rehabilitation have different focusses when reviewing the medical history and determining what constitutes a potential complication. These differences became apparent when reviewing the responses from the on-site orthotist and the combination of an orthotist / physiotherapist / occupational therapist team. It is suggested that these areas be replaced by a predefined list of choices to help focus the assessment on the needs of the orthotist.

Since the medical history, goals and complications sections were based on subject feedback, some differences could have been due to the subject supplying different information, or a different focus, during the two assessments. Problems with the speaker-phone could have also led to problems of hearing the subject.

Physical data

The physical data section recorded information on muscular function, joint function, vascular problems, and balance. For the strength measurements, individual variations were accommodated by grouping the Oxford Muscle Strength Scale values into three sections: no functional strength (0,1,2), weak functional strength (3), acceptable functional strength (4,5). Range of motion values were grouped into normal or abnormal sections. These groupings were required since orthotists typically do not perform strength and range of motion assessments in the same manner as physiotherapists. This probably occurs because physiotherapists and occupational therapists are concerned with the physical improvement of the patient while an orthotist is concerned with production of a device based on the patient's functional condition. More precise measurements would be required to show how the subject is progressing as part of treatment. Broader scales were considered sufficient by the orthotists for this study and were better aligned with current clinical orthotic practices.

The general physical measures were similar in all cases except spasticity and balance. The similar measures included sensation, unstable joints, skin problems, and vascular problems. Upon reviewing the raw data, the spasticity values were found to differ by only one level (i.e., non-mild or mild-moderate). Since the two assessments could be at different times of the day, variations in spasticity of up to one level can be expected. This possibility was supported upon review of the assessment schedule and the subject's medical condition. The difference in balance assessment cannot be accounted for with the data from this study; therefore, the assessment criteria must be modified to provide a better definition of balance.

In terms of range of motion, plantar flexion and hip extension measurements showed the largest between-assessment differences (70 percent the same). For these cases, the on-site orthotist indicated no range of motion problem but the orthotist/therapist team recorded a range of motion problem. These results could be attributed to differences in subject's position during measurement (i.e., whether the subject was measured sitting or lying down), confusion between angular conventions (i.e. is the angle measured clockwise or counter clockwise), and/or what normal values were used (i.e., what is functionally normal). The other lower limb range of motion measures had acceptable between-group similarity scores (mean = 86.0%, standard deviation = 7.1).

Strength measures were the most variable assessment results (mean = 68.8%, standard deviation = 11.21). Dorsiflexion strength was the most similar measure while inversion, hip flexion, hip extension, and hip abduction were the least similar. General trends showed that, of the ankle and knee measures that were different, the on-site orthotist rated strength higher than the orthotist/therapist team. The orthotist/therapist team generally rated the hip strength higher than the on-site orthotist. These differences were very consistent within subjects since the strength rating trends differed for only two cases over all lower limb measurements. Strength measurement discrepancies could be attributed to individual differences in the way strength is measured by an orthotist compared with a physiotherapist or occupational therapist.

Gait data

The gait data section of the clinician questionnaire described how the person walked. Since the video record from one subject was corrupted, gait data analysis was completed for 17 subjects. Discrepancies between the on-site and remote assessments were found for inversion/eversion, lateral trunk flexion, excessive knee flexion, and knee hyperextension (all with 71% similarity score). The remaining measures included foot drop, hip hike, vaulting, genu valgum or varum, protective pain gait, and rhythmic disturbance (average = 86.6, standard deviation = 6.0).

In three of four different inversion/eversion assessments, the on-site orthotist indicated inversion/eversion while the on-line orthotist did not indicate a problem. This result was consistent with the pretest sessions where the on-site orthotist consistently indicated inversion/eversion problems while the on-line orthotists did not record a problem. The clarity of the video may have been a factor for picking up fine motions, such as inversion/eversion. Since only two to three walking strides were captured, the inversion/eversion problems may not have been available in the video clip. Often inversion/eversion problems are due to fatigue and take some time to notice. The on-line orthotist must rely on the on-site therapist to choose a representative video clip for analysis.

For lateral trunk flexion, the orthotist/therapist team consistently indicated that excessive lateral bending occurred. The on-site orthotist only indicated excessive lateral bending for one client. This difference could be attributed to the availability of a frontal-view video tape for the remote orthotic assessment. It may be easier to identify excessive lateral trunk bending by slowing a video clip or stopping the video to look at representative images during the gait cycle.

Most of the excessive knee flexion and knee hyperextension discrepancies were found on the last clinic visit and occurred with subjects that had numerous gait deviations. No pattern was found for between-clinician differences at the knee.

Computer assessment results

The data for all four Mobile Clinic trips were included in the computer assessment analysis since data from the first trip helped show the progression from a novice to an experienced user. The temporal results are shown in Table 1.

Improvement in remote assessment efficiency was shown for the first three trials. In fact, almost 50 percent improvement occurred between the first and third sessions. Results from the third session were comparable with the time required to do an on-site assessment. For the fourth trial, some telecommunication problems adversely affected the time required to complete each assessment. The communication system, had to be restarted many times due to bad telephone connections.

These results show the importance of training. A medical distance communication system should not be expected to work at peak efficiency during the first session. Staff training on using the computer, using the distance communication tools, and "live" practice sessions are essential to

Table 1. Computer and off-line time for orthotic assessments

Trip	Measure (min)	Mean	Std Dev
1	Computer time	83.75	38.60
	Off-line time	13.75	4.79
2	Computer time	53.33	15.38
	Off-line time	12.50	2.74
3	Computer time	43.33	16.02
	Off-line time	15.00	0.00
4	Computer time	60.83	14.29
	Off-line time	27.50	12.14
All	Computer time	58.18	23.98
	Off-line time	17.50	8.96

optimize the distance communication process.

The system ratings also improved between sessions. None of the measures had poor ratings and below average ratings were only recorded for the first session. The majority of responses were above average or excellent in all areas except ease of assessment and confidence of assessment (Table 2). It was not surprising that the on-line orthotist considered the ease of assessment and assessment confidence to be average since the distance communication system should be at least as good as a regular assessment. Cases where the rating was above average or excellent may be related to improved gait analysis tools or obtaining a different perspective from the remote clinician. Subjectively, it appeared that the expectations of the on-line orthotist may have increased as the study progressed. Increased expectations, in association with telecommunication problems, may account for the less favourable overall satisfaction rating in trial four.

Debriefing

A series of questions related to the distance communication system, system training, clinical factors, and future possibilities were answered during the debriefing session. While issues raised during this session are covered in discussion, the following factors should be emphasised:

- distance communication should provide more efficient and more available rehabilitation services for remote communities;
- a reliable modem connection does not always occur (i.e., the modem may disconnect during a session);
- a good quality speaker-phone is essential;
- adequate time must be given to learn how to use the communication system and to develop confidence in the measurements/ information;
- an on-site technical person should be designated to provide hardware and software support;
- this technology is also applicable to other areas of physical rehabilitation.

Discussion

The results and debriefing feedback supported the use of distance communication technology for remote orthotic assessment. While it is recognised that a larger sample size is required to ensure that this assessment method is valid, these test results have provided insight regarding system requirements, setup, and clinical considerations.

The computer distance communication system used in this study was an effective tool for remote orthotic assessment. The P2P software and hardware provided some setup difficulties; however, it provided an effective means of sharing images between sites using a variety of communication protocols (i.e., modem, Internet).

Of prime importance was the ability of the central orthotist to see the client "live". Even with the slow frame rate, the consulting orthotist considered the verbal and visual interactions with the client to be an essential part of the assessment. By seeing the client, the orthotist could perceive nonverbal feedback that may not be expressed in a verbal exchange. This visual feedback provided insight into the person's status. The orthotist could also monitor any measurements or interventions that were done at the remote site. Since live-video uses much of the available bandwidth, the live-video mode was often deactivated to increase overall system performance. Improvements in data compression and data transfer rates should improve live-video speed and quality.

While video is essential for adding a personal element to the assessment session, the

Table 2. Responses from computer assessment questionnaire (% of responses from all trips)

Measure	Below average	Average	Above average	Excellent
Ease of use	18.2	4.5	63.6	13.6
Ability to understand remote person	4.5	9.1	27.3	59.1
Ease of assessment	13.6	59.1	18.2	9.1
Confidence in assessment results	13.6	45.5	18.2	22.7
Overall satisfaction	–	13.6	59.1	27.3

Chalkboard feature was the most beneficial for discussions and system training. The Chalkboard was typically used to discuss captured still images, reference images, or to learn how to use related programmes or features. Once a person knows how to turn the system on and use the Chalkboard, most other system functions can be taught on-line.

A low-end speaker-phone proved to be unacceptable for interactive clinical assessments. Since the clinic area may have background noise, more than one person will be involved with the assessment, and the subject may not be close to the speaker-phone (i.e., on an assessment table), a good quality audio system is required. Language problems (french/english) were exacerbated with inferior audio quality. An ideal full-duplex system would detect sound from at least three meters away and play back the sound with a quality comparable to a regular telephone conversation. The system should also function well during a conference call.

The clinician's efficiency and confidence with the system improved over the four test trials. This improvement could be attributed to growing experience with the communication system and with general computer operations. The quality of interactions between the remote therapist and the on-line orthotist may have also improved throughout the study.

While the distance assessment pilot testing was successful, improvements could be made in certain areas. These areas included medical history, prescription and complicating factors, spasticity, range of motion, and strength. Discrepancies between the on-site and on-line orthotists could be attributed to:

- the subjects being assessed as part of the study and not necessarily because of a specific problem. If a specific problem existed, the assessment would be more focussed and related reference documents would be present (i.e., prescription, referral, related medical history);
- measurement, interpretation and clinical techniques vary between fields of orthotics, physiotherapy and occupational therapy. These differences can especially affect strength and range of motion measurements and reporting;
- a client could give different information during an interview with a familiar therapist than an orthotist they are meeting for the first time;
- personal differences in interpretation can adversely affect gait analysis results;
- since the two assessments occurred at different times in the day, the person's strength and range of motion may vary. The patient may also give a different focus to the medical history depending on when they are interviewed;
- poor audio quality could adversely affect interview responses;
- video quality may make it difficult to detect small variances in walking gait. Care must be taken to videotape the user in the best conditions (i.e., good lighting, camera angle, lift trousers up to show brace, etc.). The orthotist must also rely on the remote therapist to select an appropriate video clip for analysis.

Inter-assessment discrepancies for range of motion, strength, and gait analysis showed consistent trends. These trends involved one group reporting slightly higher results than the other group (usually within one rating). Since the differences are consistent, the discrepancies are likely protocol or interpretation related as opposed to random error. Further instruction should help coordinate these assessment results.

An on-line database was an effective tool for remote orthotic assessment. The assessment database provided a consistent method of approaching an orthotic problem. This consistency should reduce communication errors due to terminology, measurement technique, or data entry methods. To achieve this consistency, staff at the remote and central sites must be adequately trained with the assessment protocol. Without adequate training, inter-discipline differences could affect the test results. This database/training combination is very important when providing consulting services to a variety of remote locations. As distance communication technology is adapted to different fields, databases and protocols specific to the discipline are required to accommodate different assessment perspectives.

The need for a good rapport between the central and remote clinicians was frequently mentioned as an important factor. Clinicians will work in a much more efficient and accurate manner when they understand how each other works, know the other person's abilities, and know how each other uses the distance communication tools. Since the consulting clinician must rely on the remote clinician as an extension of his or her hands and clinical eye, confidence in each others skills is essential to prolonged success. The project clinicians suggested that face-to-face meetings/educational sessions would help maintain a confident medical distance communication relationship.

Other initiatives that would benefit a distance communication programme include designation of on-site technical expertise, scheduling of regular on-line sessions, and organizing a network of expertise between centres. While the consulting site should assume some leadership regarding the technical aspects of setting up, using, and maintaining the computerized communication system, developing on-site experience with system use and maintenance is important. The on-site technical person would help train new people on the system, help troubleshoot problems, and help integrate the system into hospital specific networking initiatives. The technical person would also support communications between other remote sites (i.e., communications that do not involve the central rehabilitation site).

A regular on-line consultation session would be beneficial from a scheduling and skill maintenance perspective. If regular on-line rounds or on-line clinics were scheduled, both sites could be assured that the appropriate clinicians are present for consultation. This time could also be used for educational sessions. Regular on-line communications would also ensure that the remote clinicians maintain their computer system skills. While these interactions would be beneficial to the patient and medical professional, long-term funding and resources for these on-line clinics and consultations must be considered.

In addition to consultations with a specialized rehabilitation centre, the remote hospitals could connect with each other to share local expertise or hold meetings. On-line meetings would work best if limited to two sites with no more than four people around the computer screen.

Conclusion

Based on the test results and the clinician feedback, computerized distance communication can be considered an appropriate technology for consultations in orthotics and many areas of physical rehabilitation. The low-cost solution presented in this report should make remote assessment accessible by most clinics in Canada since existing communication lines can be used, low-end computers are required, and the system is easy to use. Methods for applying this technology could also be exported internationally so that developing countries may take advantage of foreign medical expertise.

While this assessment approach was considered effective, assessment discrepancies were found between clinicians. To reduce the chance of communication error a consistent and reliable assessment protocol should be employed. This protocol would be enhanced by maintaining a rapport between the remote and central rehabilitation sites. An evaluation of assessment/follow-up reliability with a larger sample size should be performed; however, many sites must be on-line to provide the subject base to carry out such a project.

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References

Allen A, Hayes (1994). Patient satisfaction with telemedicine in a rural clinic. *Am J Public Health* **84**, 1693.

Ball K (1994). Riding the superhighway of education with video teleconferencing. *Minimal Invas Surg Nurs* **8**, 114-115.

Berger N, Edelstein JE, Fishman S, Hoffman E, Kaufman M, Kretzs D, Springer WP (1981). Lower limb orthotics: including orthotists' supplement. – New York: New York University Medical Center

Bergman R (1994). The world at their fingertips: rural providers turn to Internet. *Hosp Health Netw* **68(14)**, 52.

CARLSON B (1994). Telemedicine comes of age. *Alabama Med* **94(3)**, 11-18.

CHAVES-CARBALLO E (1992). Diagnosis of childhood migraine by compressed interactive video. *Kansas Med* **93**, 353.

DUMAY ACM (1995). Medicine in virtual environments. *Technol Health Care* **3**, 75-89.

ENGLAND CF, FANNIN RF, SKAHAN JE, SMITH HW (1977). A manual of lower extremity orthotics./edited by MH Anderson. – Springfield: CC Thomas.

FERRER-ROCA O, DIAZ-CARDAMA A, PITTI S, RAMOS A, GOMEZ E, TEJERA A, SPENCER J (1995). Telemedicine in the Canary Islands. *Lancer May 6* **354**, 1177-1178.

GREENE G (1993). The Terry Fox Mobile Clinic: out-reach rehabilitation in eastern and northern Ontario. *Can J Rehabil* **6**, 219-224.

HUBBLE JP, PAHWA R, MICHALEK DK, THOMAS C, KOLLER WC (1993). Interactive video conferencing: a means of providing interim care to Parkinson's disease patients. *Mov Disord* **8**, 380-382.

JENNETT PA, WATANABE M, HALL WG (1995). The use of advanced computer technology to enhance access to health care and to respond to community needs: the results of the evaluation of a technology-based clinical consultation service. In: MEDINFO 95; proceedings./edited by RA Greenes. **8(2)**, 1497-1481.

JEROME L (1993). Assessment by telemedicine (Letter). *Hosp Community Psychiatry* **44(1)**, 81.

KAYSER K, DRLICEK M (1992). Visual telecommunication for expert consultation of intraoperative sections. *Zentralbl Pathol* **138**, 395-398.

LEMAIRE ED (1993). Distance education technology for prosthetic CAD/CAM instruction. *J Prosthet Orthot* **5**, 82-87.

LEMAIRE ED, JEFFREYS Y, MORAZAIN G, GREENE G (1977). A model for remote lower-extremity orthotic assessment and modification using distance communication technology. *Saudi J Disabil Rehabil* **3(1)**, 1-13.

LEWIS M, BOYD MOIR AT (1995). Medical telematics and telemedicine: an agenda for research evaluation in Scotland. *Health Bull (Edinb)* **53**, 129-137.

LING R (1993). Telemedicine: treating the patient by remote control. *Jr Nav Med Serv* **79**, 145-147.

McCollough NC, Fryer CM, Glancy J (1970). A new approach to patient analysis for orthotic prescription – part 1: the lower extremity. *Artificial Limbs* **14(2)**, 68-80.

McNamara DM (1994). Health-orientated telecommunication: a community resource. *Nurs Manage* **25(12)**, 40-41.

PADEKEN D, SOTIRIOU D, BODDY K, GERZER R (1995). Health care in remote areas. *J Med Syst* **19**, 69-76.

PEREDNIA DA, ALLEN A (1995). Telemedicine technology and clinical applications. *JAMA* **273(6)**, 483-488.

PEREDNIA DA, BROWN NA (1995). Teledermatology: one application of telemedicine. *Bull Med Libr Assoc* **83**, 42-47.

PUSHKIN DS (1992). Telecommunications in rural America: opportunities and challenges for the health care system. *Ann NY Acad Sci* **670**, 67-75.

RAFUSE J (1994). University of Alberta program links northern hepatitis patients with southern consultants. *Can Med Assoc J* **151**, 654-655.

REPONEN J, LÄHDE S, TERVONEN O, ILKKO E, RISSANENT T, SURAMO I (1995). Low-cost digital teleradiology. *Eur J Radiol* **19**, 226-31.

SANDERS JH, TEDESCO FJ (1993). Telemedicine: bringing medical care to isolated communities. *J Med Assoc Ga* **82**, 237-241.

SARRAFIAN SK (1985). Functional anatomy of the upper limb. In: Atlas of orthotics: biomechanical principles and application./ American Academy of Orthopedic Surgeons. – St. Louis: CV Mosby. p35-41.

SATAVA RM (1995[a]). Medical applications of virtual reality. *J Med Syst* **19**, 275-280.

SATAVA RM (1995[b]). Virtual reality and telepresence for military medicine. *Comput Biol Med* **25**, 229-236.

SOLOMON PA, TORMA MJ, STRICKLAND RM, MARTIN PS, CASON V, ANDERSON D, RAINWATER P, STERNS B (1996). Dermatology screening with telemedicine (Letter). *J Fam Pract* **42**, 84-85.

VON HANWEHR R, POPESCU GF, TAYLOR HE, WINKLER KH, SWENBERG CE (1995). Interventional telemedicine for noninvasive neuroradiosurgery: remote-site high-performance computing, mathematical optimization, and virtual scenario simulation. *J Med Syst* **19**, 219-262.

WEBER D (1990). Clinical aspects of lower extremity orthotics. *Elgan Enterprises* p83-86.

WILLIAMS ME, RICKETTS TC, THOMPSON BG (1995). Telemedicine and geriatrics: back to the future. *J Am Geriatr Soc* **43**, 1047-1051.

WILSON KG, CRUPI CD, GREENE G, GAULIN-JONES B, DEHOUX E, KOROL CT (1995). Consumer satisfaction with a rehabilitation out-reach program. *Arch Rehabil Med* **76**, 899-904.

WITTSON CL, AFFLECK DC, JOHNSON V (1961). Two-way television group therapy. *Ment Hosp* **12**, 22-23.