Technical Feasibility of Remote Assessments for Rehabilitation

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Abstract

Background: Technical feasibility was evaluated for conducting standard motor assessment instruments in a remote setting. Remote assessment was compared to co-located assessment for five evaluation instruments. Developing teleassessment methods is important for delivering rehabilitation services to those whose access is limited by distance or the ability to travel to comprehensive rehabilitation clinics. The five clinical measures utilized were joint Range of Motion (ROM), Manual Muscle Test (MMT), Berg Sit-to-Stand, Berg Forward Reach and the Timed Up and Go (TUG). Subjects without impairments participated, but were given simulated impairments to mimic the patient population commonly seen in rehabilitation clinics. Methods: Co-located and remote rooms were in the same building, connected by broadband video and audio. Ten subjects participated. One therapist performed all co-located testing while another performed all remote assessments. The two therapists were blinded to each others’ test results. Measurements followed standard clinical methods. Data was analyzed using repeated measures ANOVA and paired t-tests. Results: No significant differences were found between co-located and remote assessments, but the power to detect small differences was low. Conclusions: Remote application of several clinical test instruments was shown to be technically feasible. A clinical study with patients is needed to determine efficacy, reliability and validity of remote assessment.

Keywords: telerehabilitation, telehealth, teleassessment, consultation, physical therapy

INTRODUCTION

Telehealth is experiencing rapid growth with new clinical applications and new technology products appearing daily. Telerehabilitation, a subset of telehealth, is the provision of rehabilitation services delivered at a distance using videoconferencing and other telehealth technologies. These services include evaluation and treatment, as well as education, consultation and coordination of care. Telerehabilitation remains in the formative stage with a growing body of research but with little impact to date on clinical practice. The state of telerehabilitation has been recently reviewed several times [1-4] and has been the subject of two special issues [5, 6] The reviews describe the promise of telerehabilitation and list a growing number of research projects, but are not able to cite examples where telerehabilitation is used on a regular clinical basis. This mirrors the broader picture of telehealth where a recent meta-review found only a few controlled trials comparing telemedicine with face-to-face patient care, and while those studies demonstrated technical feasibility, they did not show an obvious clinical benefit for telehealth [7]. However, because there is great potential for telerehabilitation to make a significant impact on healthcare, and potential for telerehabilitation to save money [8], there is a continuing need for studies that explore new ways of delivering mainstream rehabilitation assessment and therapies using telerehabilitation technologies.

Telerehabilitation has been offered in limited settings in all areas of rehabilitation. For example, physiatry services have been offered via telehealth technology at the University of Tennessee Medical Center [9]. Remote speech therapy has been delivered to rural
schools in Oklahoma [10]. Occupational therapists have used telerehabilitation methods to deliver cognitive therapy to individuals with traumatic brain injury [11], and interventions to prevent pressure ulcers have been delivered to individuals with spinal cord injury [12, 13]. Virtual reality tools have been merged with telerehabilitation [14, 15].

Physical therapy rehabilitation services have also been provided via telehealth technology. In Australia, individuals who have undergone total knee replacements, have completed their post-operative rehabilitation remotely [16]. Consultative services in pediatrics have been conducted in the Netherlands [17]. Orthotic assessments [18] and consultations [19] have been conducted using low-bandwidth telemedicine. Physical therapy has been provided to individuals with traumatic brain injury [20]. Telerehabilitation has been used for community-based stroke rehabilitation [21, 22]. Bimonthly physical therapy teleclinics are conducted for patients in rural Minnesota and on the Pacific Rim island of American Samoa from a metropolitan rehabilitation center in Minnesota [23], resulting in positive clinical outcomes and patient satisfaction [24].

Measuring the effectiveness of any rehabilitative intervention depends on tests that are reliable and valid. Assessment tools are readily available to rehabilitation clinicians in the traditional on-site setting. However, one may not assume that these standard measures can be used effectively via telehealth technologies. To date, only a handful of studies have investigated standard tests applied to telerehabilitation. In one pilot study, the Kohlman Evaluation in Living Skills and the Canadian Occupational Performance Measure, tests used by occupational therapists, were reported to have agreement when completed in-person and remotely [25]. The NIH stroke scale was shown to have good reliability when administered remotely [26]. Internet-based assessment of motor speech disorders, including the Frechay Dysarthria Assessment and the Assessment of Intelligibility of Dysarthric Speech instruments were shown to generally agree with face-to-face assessments [27]. Measuring knee angle remotely from captured still pictures using a computer program that calculated joint angles showed good agreement with measuring knee angle in person with a universal goniometer [28].

Functional assessment using standardized instruments that are reliable and verified is an essential part of any rehabilitation treatment program. Teleassessment could be an effective means for conducting functional assessments for remote populations and for those for whom transportation is a significant barrier. A valid, reliable teleassessment service would be particularly valuable for patients who need periodic assessments to determine treatment progress or to determine if they meet criteria to be admitted into a specialized rehabilitation program.

The long range goal of this research is to determine if standard assessment measures used by physical therapists can be conducted with the patient located far from the therapist. The specific objective of this study was to investigate the technical feasibility of teleassessment by determining whether the results of standard assessments conducted remotely were the same as the results of the same assessments conducted in-person, in a co-located mode.
There are hundreds of methods and instruments used to assess motor function. We selected a subset of standard assessment instruments to include in this study. The test instruments were selected from measurements that are: 1) published measurement tools, 2) reliable and valid, 3) used widely by physical therapists, and 4) supported by standard instructions for administration and scoring. The instruments also needed to be likely to reveal the strengths and weaknesses of the telehealth approach. We also wanted to include tests of physical impairment as well as functional ability. Five physical rehabilitation outcomes assessment instruments were selected: range of motion, manual muscle test, Berg Sit-to-Stand, Berg Functional Reach, and the Timed Up and Go.

In the study, healthy volunteers participated as patients with simulated impairments to see if the technology and methods were feasible. Additional healthy volunteers acted as simulated caregivers, following directions given by the remote physical therapist using videoconferencing technology. Simulated patients and caregivers were used because in this pilot we were interested in assessing the usability of the technology and the feasibility of teleassessment methods, including whether caregivers and patients could be instructed to administer the tests. Determining feasibility under these conditions is a necessary step before proving efficacy in a clinical trial.

**METHODS**

**Remote assessment technology**

The technology layout for remote assessment is shown in Figure 1. For the remote assessments, the evaluating therapist was in a different part of the building, connected to the examination room by a videoconferencing system (Polycomm, ViewStation) that provided high quality voice and video over a broadband network. The therapist could remotely pan, tilt, and zoom the camera on the patient’s end. A video capture unit (Hauppauge, USB-Live) captured the video image on the therapist’s computer for taking and storing snapshots. A custom digital dynamometer (force sensor) was connected to the serial port of the remote PC through a sensor interface unit. The sensor readings were transmitted over the network to the therapist’s computer. As the caregiver pressed on the patient’s limb with the dynamometer, a bar graph on the therapist’s computer indicated the force level in real-time. The program to acquire and communicate force data over the network was written in Visual Basic. For ROM measurements, a virtual goniometer image processing program was developed for the therapist’s computer to aid in measuring joint angles (Figure 2). Video snapshots were taken by the therapist of the subject positioned at the desired angle. The snapshots were later imported into the angle analysis program where the therapist could click on the subjects’ bony landmarks to position a virtual goniometer. When the therapist was satisfied with goniometer placement, the program calculated the joint angle.

*Figure 1 about here*

*Figure 2 about here*
Subjects
Ten subjects (2 male, 8 female, ages 18-35) were enrolled in the study. An additional ten subjects (4 male, 6 female, ages 18-35) participated as simulated caregivers and were present in the examination room during remote assessment sessions. None of the simulated caregivers had experience with the assessment tools. For each assessment, the subjects were given the simulated impairment described in the following section. The level of impairment was different for each subject. Two licensed physical therapists with over 10 years of clinical experience conducted the assessments. One completed all co-located measurements while the other conducted all remote measurements. The project was approved by the appropriate Institutional Review Boards, and informed consent was obtained from all subjects.

Assessments
Five assessments were studied, Range of Motion (ROM) of the shoulder and knee, Manual Muscle Test (MMT) of the biceps and quadriceps, two components of the Berg Balance Test (Item 1: Sit-to-Stand and Item 8: Forward Reach) and the Timed Up and Go (TUG). The TUG is a quick, practical method for testing basic mobility [29, 30]. The Berg Balance Scale is a comprehensive, objective measure of balance abilities [31-33]. Limiting the Berg Balance Test to two of its 14 items was done to save time. The selected items are representative of the assessment methods needed for the Berg Test. Each assessment was conducted using traditional co-located methods, and again using one or more teleassessment methods. For the remote assessments, the therapist gave scripted, verbal instructions to the patient and caregiver on how the test should be performed. Figure 3 shows representative samples of the assessments and simulated impairments.

ROM assessment followed the methods in Clarkson [34]. Joint motions assessed were shoulder abduction, shoulder external rotation and knee flexion. The joint angle was set to a randomly assigned position with a measurement jig anchored to sites proximal and distal to the joint being measured. The jig ensured consistency of joint position. Angles were randomly selected as a percentage of the subject’s full available, pain-free range in increments of 10 per cent. Three shoulder abduction, two shoulder external rotation, and two knee flexion angles were selected. The joint positions were different for each subject but the same for co-located and remote measuring.

Co-located joint position was measured by the therapist using a universal goniometer (Jamar EZ Read). Four methods of remote ROM assessment were implemented. For methods 1 and 2, the therapist instructed the caregiver on where to place the goniometer while observing via videoconferencing. For method 1, the PT zoomed the viewing camera and read the goniometer directly. For method 2, the caregiver read the number off the goniometer and reported to the therapist. For methods 3 and 4, after the subject was positioned, the PT captured the image from the viewing camera for off-line analysis. Capturing the image meant the subject did not have to hold still during goniometer manipulation. For method 3, the joint angle was determined using the virtual goniometer program described above. For method 4, the PT held a universal goniometer up to the
image on the computer screen. Both physical therapists independently measured the angles in methods 3 and 4. Joint angles were measured in degrees rounded to integers.

In-person biceps and quadriceps MMT assessment followed the methods in Clarkson [34]. Two methods of remote MMT assessment were implemented. For both, the therapist observed the testing through the videoconferencing system and instructed the subject and caregiver on how to conduct the test. For method 1, the therapist scored the MMT based solely on observing the subject push against the caregiver. Method 2 added a digital goniometer which the caregiver placed between his hand and the tested limb so that the force exerted by the patient appeared as a moving bar on the therapist’s computer. MMT was scored from 0 to 5 according to standard procedure (Clarkson). As in a standard clinic, therapists could assign a plus or minus. In the subsequent analysis a plus added 0.33 to the integer score and a minus subtracted 0.33. Subjects were provided with a simulated impairment for co-located and remote MMT assessment. Weight was added distally to mimic muscle weakness. For biceps testing, zero to 60 pounds were attached to the distal forearm. For quadriceps testing, zero to 70 pounds were added proximal to the ankle. The amount of attached weight was randomized across subjects, but for each subject the same weight was used for co-located and remote assessments.

The two items of the Berg Balance Test, followed the methods described by Berg [31]. For remote assessment, the therapist provided instruction to the subject and observed the results. Subjects were given a simulated balance impairment by standing on one or two 14” air filled rubber disks (Exertools Dynadisc, Novato CA) used for exercise and strength training. Varying the inflation pressure and stacking one or two disks adjusted the difficulty of maintaining balance. The same disk configuration was used for co-located and remote assessments. Item 1, Sit-toStand, was scored on a 0 to 4 scale following Berg instructions. For Item 8, Forward Reach, subjects reached parallel to a board with vertical rule lines that could be read by the remote therapist using the camera pan and zoom. Reach was recorded in inches and was not converted into a 0 to 4 Berg score.

The Timed Up and Go Test measures the time to rise from a chair, walk 10 feet, return and sit. TUG followed the methods described by Mathias, Nayak and Isaacs [29]. Subjects were given a simulated impairment by walking on top of a 12 foot long, 4 inch wide balance beam whose top surface was 5 inches from the floor. Timing was accomplished with a stopwatch with a resolution of 0.01 sec. Remote assessment was performed by therapist observation.

Protocol
All testing for each subject was done in a single session. Prior to the actual testing, the subject practiced the tests with the imposed impairments to minimize learning effects during testing. For the first five subjects, the co-located tests were conducted before the remote tests while for the remaining five the order was reversed. The test order was: (1) MMT Right quadriceps with first weight, (2) MMT Left quadriceps with second weight and digital dynamometer, (3) MMT R biceps with first weight, (4) MMT L biceps with second weight and digital dynamometer, (5) Berg #1 on one disk, (6) Berg #1 on two

To control repeatability of the angle setting for the ROM measurements, subjects 5 through 10 had co-located and remote assessments done without the subject changing position between trials. The subject had the angle set by the experimenter. The local therapist measured the angle with the goniometer, then left the room. The remote therapist then enabled the videoconferencing system, adjusted the camera and took a photo of the joint. Next, the remote therapist instructed the caregiver on how to place the goniometer and then zoomed in to read and record the joint angle. The remote therapist asked the caregiver to verbally report the goniometer reading which was recorded. The remote therapist then disabled the TV while the local therapist returned to the room. The process was repeated with the next angle. The joint position photographs were measured off line with the two therapists each conducting the two on-screen measurement methods.

Data analysis
The ROM experiment was a single factor design with seven levels: (1) co-located, (2) remote with caregiver reporting goniometer setting, (3) remote with therapist zooming in and reading the goniometer directly, (4) remote photo with angle measured by one therapist with a virtual goniometer, (5) remote photo with angle measured by the second therapist with a virtual goniometer, (6) remote photo with angle measured by one therapist using a universal goniometer held up to the snapshot, (7) remote photo with angle measured by the second therapist using a universal goniometer. The data was analyzed as a 70 block, repeated measures, within-subjects design [35, 36] with one block being one joint setting in one subject (7 joint settings times 10 subjects). One block had missing data and was removed from the analysis leaving 69 blocks. The null hypothesis was that measurements of a single joint position with the seven different measurement methods not differ significantly. An alpha of 0.05 was used for the critical F value in the ANOVA analysis.

Three MMT methods were compared: co-located, remote with dynamometer assist, and remote by observation only. Because only two methods were used for any one muscle and subject, the data was analyzed by paired t-tests comparing co-located with remote-dynamometer and co-located with remote-observation.

Berg Sit-to-Stand, Berg Reach and TUG were analyzed with paired t-tests comparing co-located and remote scores. For TUG, trials 1 and 2 were averaged before performing the t-test.

RESULTS
Pooling all AROM data showed a significant main effect of angle measurement method, $F = 2.46, F_{crit}(0.05) = 2.12, p = .024$. Neither the Scheffe nor the Tukey HSD multiple comparison test showed any one method standing out as significantly different from the others. Suspecting that the main effect was an artifact of inconsistent angle positioning
between co-located and remote conditions, the data was re-analyzed for just subjects 5 through 10 where the joint was guaranteed to be in the same position for all measurements. For these recordings, there was no significant difference between the measurement methods, $F = 1.69, F_{crit}(0.05) = 2.13, p = .12$. A power analysis showed the power of the experiment to detect a clinically significant angle measurement method difference of 5 degrees was 100% and the power to detect a difference of 1 degrees was 77%. To determine if one method had a consistently high or low bias or more scatter than any other, the deviation of the seven methods about the mean for each angle setting on each subject (subjects 5-10) was computed (Figure 4). The plot shows no consistent trends or patterns for any particular method. All 7 methods had an average deviation from the mean between -1 and 1 degree (no bias) and a standard deviation about the mean of 3.4 to 5.3 degrees (approximately equal scatter).

One issue was whether there was a difference in goniometer angle readings based on if the caregiver or the remote PT performed the actual reading. A paired t-test for all 10 subjects showed there was no significant difference between the two methods, $t = 1.15$, $t_{crit}(0.05, 2\text{-tail}) = 1.99, p = .25$. For 68 of the 69 observations the two methods differed by 0 or 1 degree. For one observation the methods differed by 2 degrees.

Another issue was whether using a virtual goniometer was different than holding a universal goniometer to the screen for remote assessment of digital snapshots taken during the test session. A paired t-test of the 138 observations (69 by each of two therapists) showed no significant difference between the methods, $t = .69$, $t_{crit}(0.05, 2\text{-tail}) = 1.98, p = .49$. Over all samples, after eliminating one outlier measurement, there was a mean absolute difference between the two methods of 3.9 degrees ($SD = 3.4$).

MMT data was pooled across all subjects and all applied weights. Paired t-tests showed no significant difference between co-located assessment and remote assessment by visual observation, $t = .21$, $t_{crit}(0.05, 2\text{-tail}) = 2.09, p = .83$, and no significant difference between co-located assessment and remote assessment by visual observation augmented with the digital dynamometer, $t = .39$, $t_{crit}(0.05, 2\text{-tail}) = 2.09, p = .69$. The power of the test to detect differences in MMT scores of .33 (a plus/minus increment) and 1 was 60% and 100% for co-located versus remote observation, and 51% and 100% for co-located and remote dynamometer.

Berg Sit-to-stand data was pooled across all subjects. Data from Trial 1 of each subject was not analyzed as all Berg scale scores were 4 which indicates the activity was performed safely and independently by the subject. For Trial 2, 13 of 20 observations scored a 4, with some differences between remote and co-located for the rest. A paired t-test of the Trial 2 data showed no significant difference between co-located and remote measures, $t = 2.12$, $t_{crit}(0.05, 2\text{-tail}) = 2.26, p = .06$. In the Trial 2 data, Four subjects received scores in Trial 2 that were differed between co-located and remote. Of these four, two had a remote score of zero which meant the subject stepped off the disc during the remote observation.
Berg Forward Reach data was pooled across all subjects and both trials. A paired t-test showed no significant difference between co-located and remote methods, \( t = .18, tcrit(.05, 2\text{-tail}) = 2.09, p = .85 \). A post hoc analysis showed the power of the test to detect a difference of one inch was 48\% and the power to detect a difference of two inches was 95\%. Over all the data, the average absolute value of the difference between co-located and remote measures was 1.8 inches (SD=1.5). The absolute difference for Trial 2 data, for which subjects stood on an air disk for a balance impairment, (M=2.2, SD=1.8) was almost double that of Trial 1 (M=1.4, SD=1.2). In Trial 1 subjects reached 15.5 inches on average but only 11.3 inches for Trial 2, a significant difference, \( t = 14, tcrit(.05, 2\text{-tail}) = 2.26, p = .00 \).

For TUG, a paired t-test of the averaged trials showed no significant difference between co-located and remote methods of timing, \( t = 1.37, tcrit(.05, 2\text{-tail}) = 2.26, p = .20 \). The power of the test to detect differences of 1 sec was 32\% and the power to detect differences of 2 sec was 85\%. When the data was resorted by observation order, they showed that most subjects improved their TUG score with each successive trial, demonstrating that a learning effect persisted during the trials.

**DISCUSSION**

The study demonstrated that remote assessment is technically feasible for the selected assessment instruments and that the instruments can be implemented in tele-mode in a clinical study to prove efficacy and validity. The study illustrated several new findings about teleassessment.

**Communication bandwidth**

Caregivers and patients understood and carried out instructions provided by the remote therapist. A high quality, real-time audio link was essential for this communication. The video link back to the therapist was needed so that the therapist could visually confirm that instructions were being carried out and to record observations based on assessment measures. Video in the other direction was not required, but may help in patient interactions.

The quality of the teleconferencing video and audio impacts the accuracy of remote assessment [37]. This study used only television quality audio and video and a pan/tilt/zoom camera. For remote assessments done in the home, the quality of the video will degrade based on what available phone lines can transmit, unless the home has broadband access. Another study is needed to measure the effect of video quality on remote measurement methods. For example, the administration of the Gait Assessment Rating Scale has been reported to be as accurate using store-and-forward video clips transmitted at 128 kbps and 18 kbps compared to the full-resolution video camera clips (Russell, 2003).

**ROM**

Remote measurement of joint angles is feasible as the results showed that remote measures did not differ from co-located measures. Caregivers can be instructed to place
and read a universal goniometer. The method of reading the goniometer by zooming was less useful as it required a pan/tilt/zoom camera with good optics, and the process of zooming is time consuming. The method of taking a snapshot for later measurement was shown to be feasible, assuming that the camera could be positioned so that its axis aligned with that of the patient’s joint to avoid parallax errors. In this study, subjects sat or lay on a motorized plinth that could be raised and lowered for optimum positioning. This positioning was done quickly and grossly with the remote therapist approximating the axis of the joint to the camera height. This demonstrates that the set up time for the measurements need not be long or particularly detailed. Still, a mechanized hi-lo mat would not be available in most patients’ homes.

The therapists had no difficulty in identifying anatomic landmarks for angle measurements from digital snapshots. Although using real and virtual goniometers to measure the photos were equivalent, the virtual was easier to use. If clear video and good camera angle is possible, having the remote therapist conduct ROM measurements from a photograph means fewer instructions to the caregiver, less time for the patient to hold a position and reduced potential for error. Using a universal goniometer does have the advantage of simplicity in that it does not require custom software.

**MMT**

The remote therapist was able score manual muscle tests reliably based on observation alone. MMT scores are differentiated by the ability to maintain position against “maximal”, “moderate”, and “minimal” resistance by the therapist [34] which could be detected by the therapist by observing the patient and the caregiver to estimate exertion. Prior to data collection, the remote and local therapists calibrated their in-person MMT scoring methods to ensure inter-rater reliability. While the digital dynamometer did not appear to impact the ability to measure, it may give the remote therapist a sense of being more in control and eliminates the need for the therapist to estimate the resistance force being applied by the caregiver. The dynamometer may also be more helpful for a less experienced clinician who may require more feedback than visual observation of a test being conducted.

**Balance**

Scoring of the Berg Item #1 (sit-to-stand) is based solely on visual observation, and the resulting close match between co-located and remote scores was expected. All of the subjects were able to stand safely and independently on a single disk which explains why all Trial 1 scores were 4 for remote and local assessment. The difficulty with making inferences from the second set of trials is that there is no guarantee that the remote and local therapists were observing the same performance. Standing on two balance disks, a subject might balance well during the co-located trial (score = 4) and step off the disk when attempting the same task for the remote trial (score = 0). Thus, variations in the Sit-to-Stand scores most likely resulted from trial-to-trial variation.

Video observation was effective in assessing Berg Item #8 (Functional Reach). The larger variation of Trial 2 data resulted from subjects being given a balance impairment which likely resulted in a larger variation in their performance for collocated and remote
trials. With a zoom camera and ruled backing board, the remote therapist could record reach data, but as with co-located observation, sometimes it was difficult to determine exactly when a patient was done reaching. Adding additional technology could eliminate the ruled board and camera zooming. Or, the remote video could be recorded for off-line analysis of reach.

**TUG**

It was relatively easy for the remote therapist to observe and time the TUG after the camera was oriented for a good view of the chair and walkway. The power to detect differences of one second was low but this may have been because the subjects walked faster on each successive trial as they learned how to balance on the beam.

**Technology**

There are two strategies for remote assessments. An entirely new set of technology-based assessment measures could be developed that would be uniquely amenable to tele implementation, or existing methods used in traditional clinical settings could be tailored for use in telerehabilitation. We chose the second strategy so that assessment instruments would differ little from how they are routinely implemented in a clinic. Other than video conferencing equipment, very little technology was used.

More technology could easily be added to support more accurate measurement while keeping the essentials of the measurement instrument the same. The digital dynamometer is one example. Recording the data in pounds from the digital dynamometer might help the therapist to assign an MMT score. However, actual resistance in pounds is only a part of the MMT score because there is a large variation in how many pounds a person can produce based on their body type. An MMT score takes into account a person’s body type, ability to move a limb against gravity and ability to move against manual resistance. If this information can be gathered through observation, adding a digital force reading in pounds may assist the therapist in assigning a 0 to 5 MMT score.

A pressure sensor on the chair could detect the start and end of a TUG test, and a range sensor could record forward reach. While these sensors can be small, light, wireless and easy to use, they would require additional training for the therapist. Whether this would lead to faster, simpler, and more reliable remote assessments than when using video conferencing alone remains to be seen.

**Limitations**

Subjects were non-impaired and their simulated impairments were clearly different from the impairments seen in actual patients. For example, the repeatability of performance of persons with simulated impairments is different from patients with real impairments. For example, subjects with simulated impairments could fall off the Dynadiscs with no consequences while elderly patients with balance impairments must be caught by the caregiver. Subjects acting as patients and caregivers were highly educated and had no trouble following instructions. This may not be the case for some real patients and their caregivers. Communication with real patients and caregivers may be affected by comfort levels for talking with health care professionals or cognitive issues resultant to neurologic
insult. For the purposes of the study, however, the simulated impairments were successful in eliciting the range of assessment scores that would be expected in a clinical population.

The small number of subjects limited the power to detect Type II errors, however, it was adequate to investigate technical feasibility of the teleassessment methods. A study to prove clinical feasibility will require more subjects and this pilot can be used in a power analysis to determine the number of subjects needed in future clinical studies.

Trial-to-trial variation in task performance may have contaminated the results. Because subjects’ performance on the tests changed during testing, it is difficult to determine whether difference is test results was due to the test method or the actual performance of the subjects. To alleviate this problem, in future studies, co-located and remote test methods should be conducted simultaneously or measures should be taken to ensure performance repeatability.

Inter-rater reliability for teleassessment must be determined. In this study, one physical therapist conducted all of the co-located assessments, and a second conducted all of the remote assessments. A future study should include several therapists to measure reliability.

**CONCLUSION**

Remote rehabilitation assessment using traditional assessment instruments is technically feasible. Assessments administered remotely were conducted without difficulty and yielded approximately the same results as when administered locally. A clinical study with rehabilitation patients is needed to determine the efficacy and reliability of the test instruments with a patient population.

A high quality, two-way audio link, as least as good as a standard telephone connection, is required for effective verbal communication. For clinical observations, one-way video is essential, but the quality requirements for the video link have yet to be determined. For remote range of motion testing, the most efficient and reliable method was to photograph the subject and use a virtual goniometer to locate anatomic landmarks and measure joint angles. Aligning the camera axis with the joint axis is necessary for accurate measurement. Instructing the caregiver to place and read a goniometer is acceptable but may take longer to implement because instructions to the caregiver need to be conveyed and understood. Remote MMT is technically feasible, but testing with patients is needed before fully understanding the consequences of having no physical contact between the therapist and patient. Sit-to-Stand, and TUG can be readily implemented remotely as scoring is based on observation that does not require acute visualization. Assessing the ability to reach is based on observation but reading the distance of reach requires a good video link.

The remote assessment methods could be enhanced by additional technology, however, this would increase the expense of remote assessment and would require additional therapist training. Studies that use only videoconferencing technology with patients will
reveal more about whether more assessment technology would be useful in a clinical setting. No conclusions could be drawn about whether teleassessment can be done safely at home with just the patient and caregiver present.

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REFERENCES


Figure 1: Technology layout. Physical therapist (PT) in one room with a teleconferencing system and the ability to capture video snapshots on the PC. Simulated patient (P) and caregiver (CG) in another room with the other end of the teleconferencing system and a digital dynamometer interfaced to the PC. The PCs and video conferencing system were connected over a high-speed network.
Figure 2: Virtual goniometer. After the patient position is set, the therapist captures a snapshot from the televideo and stores on the local PC. Later, the image is brought into the virtual goniometer application where the therapist marks anatomic landmarks with the cursor and the angle is automatically calculated.
Figure 3: Assessment methods and simulated impairments. Clockwise from upper left: ROM, TUG, reach, MMT (with digital dynamometer).
Figure 4: Angle measurement data shown as deviations about the mean for each of seven methods (one line per method). The mean was computed for each angle setting on each subject for subjects 5-10.