Telerehabilitation and Electrical Stimulation: An Occupation-Based, Client-Centered Stroke Intervention

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KEY WORDS
- activities of daily living
- electric stimulation
- stroke
- task performance and analysis
- telemedicine
- user-computer interface

OBJECTIVE. We examined the efficacy of a remotely based arm rehabilitation regimen. A 62-year-old man participated in occupation-based, task-specific practice of activities of daily living (ADLs) >3 years after stroke. The entire regimen was administered over the Internet using personal computer–based cameras and free network meeting software.

METHOD. Fugl-Meyer Assessment (FM), Action Research Arm Test (ARA), and Canadian Occupational Performance Measure (COPM) were administered before intervention. One week after treatment, FM, ARA, and COPM were readministered.

RESULTS. The participant exhibited reduced impairment and reduced functional limitation. He also expressed enhanced satisfaction with his ability to perform ADLs and rated his ADL performance better after intervention. The participant could now drive using both hands, use eating utensils, and catch and throw a ball.

CONCLUSION. Data suggest feasibility and efficacy of a remotely based, inexpensive approach using functional electrical stimulation for affected arm rehabilitation after stroke.

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Stroke is a common disability with a growing number of people who have survived this neurological event. As the stroke population expands, occupational therapists need to determine effective rehabilitation interventions. Two areas of concern continue to inhibit patients from receiving rehabilitation interventions. First, there is little conclusive evidence as to the best treatment interventions. Second, patients are not receiving the expected amount of treatment. To substantially affect our patients' lives and enable stroke patients to engage in occupation, occupational therapists need to determine effective and efficient ways to treat this population.

Introduction to Stroke Rehabilitation

Stroke is the leading cause of disability in the United States (Centers for Disease Control and Prevention [CDC], 2007), with 5.8 million people who have had a stroke and 780,000 new strokes occurring annually (American Heart Association, 2008). Thirty percent of patients with stroke exhibit chronic deficits, such as functional limitations and an inability to perform activities of daily living (ADLs; CDC, 2001). However, only 30.7% of patients receive outpatient rehabilitation, with minimal time spent engaging in client-centered, occupation-based, meaningful activities (Mackey, Ada, Heard, & Adams, 1996). According to the CDC, patients having survived a stroke may experience enhanced functional abilities if they receive the expected rehabilitation as governed by clinical practice guideline recommendations (CDC, 2007). Telerehabilitation may be a viable treatment option for occupational therapists to use to meet this need.

Stroke Rehabilitation Treatment Options

Many traditional stroke intervention studies report inconclusive results, suggesting that traditional therapy is suboptimal for stroke rehabilitation. Splinting, neurodevelopmental treatment, electromyography (EMG), biofeedback, repetitive task-specific technique, sensorimotor training, and mental practice studies have all reported inconclusive results in the literature (Foley, Teasell, Jutai, Bhogal, & Kruger, 2007). Despite the inconclusive outcome studies, repetitive, task-specific practice incorporating the affected upper extremity has been shown to elicit neuroplastic changes and increase motor function (Nudo, 2007). However, rather than using repetitive, task-specific, occupation-based techniques with the affected upper extremity (Mastos, Miller, Eliasoon, & Imms, 2007), therapists are often forced to use suboptimal interventions, such as compensatory strategies using the less affected upper extremity (Jorgensen et al., 1995).

The literature supports the use of nontraditional interventions for stroke rehabilitation. Constraint-induced movement therapy and modified constraint-induced therapy enhance functional abilities for chronic stroke survivors with some active wrist and hand movement (Foley et al., 2007). Foley et al. found that robotic training increases functional outcomes for the shoulder and elbow, and virtual reality increases locomotor abilities. Foley et al. also found that functional electrical stimulation (FES) increases functional abilities in the acute and chronic stroke population. Many of these interventions can be used for patients across the poststroke spectrum in multiple service locations.

Service Locations

Once patients are home, they face additional barriers, including caregiver isolation, transportation issues, limited outpatient therapy services, inability to drive, poor support systems, limited finances, and limited insurance coverage (Pound, Gompertz, & Ebrahim, 1998). These barriers limit patients' likelihood of initiating outpatient rehabilitation. According to Teasell, Foley, Bhogal, and Speechley (2007), stroke survivors exhibited ADL gains in hospital and outpatient settings, and there were no differences in ADL gains between outpatient and home therapy. This comparability among service locations suggests that home therapy may be a viable treatment option when combined with appropriate interventions.

Functional Electrical Stimulation

Several authors have reported reduced affected upper-extremity spasticity and increased active range of motion after the use of conventional, surface neuromuscular electrical stimulation (NMES; Chae et al., 1998; Powell, Pandyan, Granat, Cameron, & Stott, 1999). Conventional NMES uses an electrical current administered by means of surface electrodes placed on the upper extremity to facilitate upper-extremity movement. Cyclic NMES improves motor impairment (Scheffler & Chae, 2007). However, this form of NMES passively stimulates the muscles and limits volitional activation; therefore, little motor relearning occurs (Glanz, Klawansky, Stason, Berkey, & Chalmers, 1996). In response to this limitation, newer NMES applications have been designed to provide the patient with needed stimulation to facilitate participation in purposeful activity and ADLs. Whereas conventional NMES offers limited functional benefit (Chae & Yu, 2000), FES has been shown to increase active affected upper-extremity movement (Hendricks, Ijzerman, de Kroon, & Zilvold, 2001), increase ability to perform ADLs (Alon, Levitt, & McCarthy, 2007), and reduce affected upper-extremity spasticity (Popovic, Popovic, Sinkjaer, Stefanovic, & Schwirtlich, 2003; Ring & Rosenthal, 2005).

Current Implementation of Telerehabilitation

In recent years, telemedicine has been used considerably for medical treatment of stroke. Telemedicine is the use of medical information exchanged from one electronic site to another, via telecommunications, to improve patients' health status regarding diagnosing, treating, or following up with a patient at a distance (American Telemedicine Association, 2008). Telemedicine has led to the development of telerehabilitation (TR), which focuses on the clinical application of consultative, preventive, diagnostic, and therapeutic services via two-way interactive telecommunication technology (Wakeford, Wittman, White, & Schmeler, 2005). TR has been used for rural and local administration of tissue plasminogen activator, stroke evaluation, consulting and training, stroke consumer education, and emergent access to stroke interventions. Concurrently, pioneer studies on stroke TR have supported the use of TR in stroke treatment. Modified constraint-induced therapy (Page & Levine, 2007), functional movement training (Carey et al., 2007), upper-extremity function via virtual environment (Holden, Dyar, & Dayan-Cimadoro, 2007), virtual reality and robotics (Broeren et al., 2008; Deutsch & Mirelman, 2007; Kuttuva et al., 2006), constraint-induced movement therapy via workstations (Lum, Uswatte, Taub, Hardin, & Mark, 2006), and administration of the National Institutes of Health Stroke Scale (Shafqat, Kvedar, Guanci, Chang, & Schwamm, 1999) have all supported functional recovery from stroke by means of TR interventions. These studies are the springboard for future studies regarding stroke rehabilitation using TR.

Implementation of TR in Occupational Therapy

Few studies have addressed the use of TR in occupational therapy; however, these studies have supported the benefits of TR. The literature supports TR as a means to administer evaluations addressing home environment, functional object height (Hoffmann & Russell, 2008), functional mobility (Sanford et al., 2006), and the Kohlman Evaluation of Living Skills and Canadian Occupational Performance Measure (Dreyer, Dreyer, Shaw, & Wittman, 2001). TR has shown promising results for home occupational therapy (Hoenig et al., 2006), home mobility (Sanford et al., 2006), rural occupational therapy services (Hailey et al., 2005), and school-based special needs services (Gallagher, 2004). Clinical education via telecommunication regarding specialized burn care has also yielded benefits in occupational therapy (Smith, O'Brien, & Jakowenko, 2006).

The American Occupational Therapy Association (AOTA) has recognized TR as an appropriate means to work with clients as stated in the AOTA (2004) TR position paper. Occupational therapists can complete evaluations, such as interviews and assessments (Cooper et al., 2002), ADL observations, sitting posture, goal setting, and treatment planning (Cooper et al., 2002) by means of TR techniques. TR can also be used for therapy consultations, such as play performance (Wakeford et al., 2005) and wheelchair mobility (Cooper et al., 2002). Occupational therapists are also using telecommunications for continuing education via online courses. Areas that have yet to be addressed include using telecommunications for intervention and supervision of students and personnel.

Thus far, research suggests that TR is a viable form of service delivery for occupational therapy and stroke rehabilitation. Limited research exists on TR using FES to engage in purposeful activity in stroke survivors, supporting the implementation of this case study to determine the efficacy of such use in occupational therapy.

Current Study

Despite the promise of modalities like FES, stroke patients often experience limited access to therapy services (Demiris, Shigaki, & Schopp, 2005). TR has the potential to eliminate barriers and allow patients an opportunity to receive needed care. TR has not been used extensively in occupational therapy, but it is supported by the AOTA as an important, emerging area of practice that holds great potential in allowing access for underserved populations (Wakeford et al., 2005).

The current study examined the efficacy of a FES program administered via a neuroprosthesis and TR. The program used free network meeting software and two personal computer (PC)–mounted videocameras costing <$60. The primary study objective was to examine the efficacy of this inexpensive, remotely based rehabilitative approach in a stroke patient exhibiting stable, affected, upper-extremity impairment. We hypothesized that the occupation-based, task-specific therapy intervention would decrease upper-extremity impairment and enhance motor function and ADL performance.

Method

Design

This study used a pretest–posttest case study design. Specifically, after screening and completing a consent form approved by the host institution's institutional review board, the Fugl-Meyer Scale (FM; Fugl-Meyer, Jaasko, Leyman, Olsson, & Steglind, 1975) and Action Research Arm Test (ARA; Lyle, 1981) were administered. The tests were given in our laboratory by a lab member blinded to the intervention to be administered; administration of assessments required approximately 1.5 hr. The intervention began 1 week later and lasted for 4 weeks; posttesting was conducted 1 week after treatment end.

Sample

The participant was chosen because he was highly motivated to continue the progression of his recovery, he was willing to drive to the lab for outcome measure administration, and he was technologically proficient. To qualify for the study, the participant had to exhibit the following inclusion and exclusion criteria, respectively. The inclusion criteria were as follows: (1) no active movement in the affected wrist or fingers, (2) stroke experienced >3 months before study enrollment, (3) a score ≥70 on the Modified Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975), (4) between the ages of 35 and 85, (5) experienced one stroke, (6) discharged from all forms of physical rehabilitation, and (7) a detectable surface EMG signal ≥5 μV from the extensor carpi radialis of the affected upper extremity suggesting that the participant is able to initiate movement via an intact central nervous system communication, and (8) agreed to the terms of the study (e.g., using TR system with an insecure Internet connection). Exclusion criteria were as follows: (1) participating in any experimental rehabilitation or drug studies; (2) pregnant; (3) excessive spasticity in the more affected upper extremity, as defined as a score of ≥3 on the Modified Ashworth Spasticity Scale (Pandyan et al., 1999); (4) excessive pain in the more affected upper extremity, as measured by a score ≥5 on a 10-point visual analog scale (Cork et al., 2004); and (5) uncontrolled seizure disorders. Using these criteria, a volunteer was identified via a stroke support group. He reviewed and signed the approved consent form and began the study.

Participant

The participant was a 62-year-old man who had experienced an ischemic, left-sided stroke, as evidenced by a computed tomography scan, 3 years, 8 months, before study entry. After his stroke, the participant received inpatient rehabilitation for 4 months, where he received occupational, physical, and speech therapy for a total of 3 hr per day. For 2.5 years after inpatient rehabilitation, he attended 30-min outpatient therapy sessions, 2 to 3 days per week. In therapy, he learned compensatory strategies for cooking, driving, and functional mobility. He received cyclic NMES to his right wrist during outpatient therapy. On discharge, he was able to dress himself, perform other ADLs, and walk for short distances using a straight cane and compensatory strategies. At the time of his study entry, the participant worked full time, played in an adapted golf league, and hunted and fished in his spare time. However, he wanted to regain functional use of his affected, dominant, right upper extremity.

At pretesting, the participant's scores on the Modified Ashworth Spasticity Scale (Bohannan & Smith, 1987) for the elbow, wrist, fingers, and thumb were 1, 2, 2, and 1, respectively. He was not receiving any other therapy intervention while involved in the current study. His motor scores before and after intervention are described later. He was motivated and met study inclusion criteria and was chosen to participate in this case study.

Outcome Measures

The following outcome measures were administered for pre- and posttesting, 1 week before treatment and 1 week after treatment, respectively. The evaluator was blinded to the study design and the intervention in which participants were engaged.

The upper-extremity scale of the FM was used to determine whether affected upper-extremity impairment changes occurred after participation in the intervention. The FM assesses several dimensions of impairment, including range of motion, pain, sensation, and movement. Data arise from a 3-point ordinal scale (ranging from 0 = *cannot perform* to 2 = *can perform fully*), and items are summed to provide a maximum score of 66. The FM offers impressive test–retest reliability (total = .98–.99; subtests = .87–1.00) and construct validity (DiFabio & Badke, 1990).

The ARA (Lyle, 1981) was used to determine whether fine motor skill changes occurred in the affected hand and fingers as a result of participation. The ARA is a 19-item test divided into four categories (grasp, grip, pinch, and gross movement), with each item graded on a 4-point ordinal scale (0 = *can perform no part of the test,* 1= *performs test partially,* 2 = *completes test but takes abnormally long time or has great difficulty,* 3 = *performs test normally*) for a total possible score of 57. The test is hierarchical in that if patients are able to perform the most difficult skill in each category, they will be able to perform the other items within the category and, thus, need not be tested. The ARA has high intrarater (r = .99) and retest (r = .98) reliability and validity (Lyle, 1981; van der Lee et al., 2001).

The Canadian Occupational Performance Measure (COPM; Law et al., 1991) is an interview used to identify occupational performance problems and to measure satisfaction and importance of tasks according to the patient. After questions are asked, clients identify the following on a scale from 0 to 10: the importance of the task, their perception of their performance with skills, and their satisfaction with their performance. Once the top five activities are determined, these tasks are used to guide treatment. The test is usually administered at baseline and discharge to determine change in performance and satisfaction. A positive number represents a change for the better. A negative number represents that the person's perception of the skills has lessened. In 2004, the COPM was reported to be a valid, reliable, clinically useful, and responsive outcome measure for occupational therapy practitioners and researchers (Phipps & Richardson, 2007).

Apparatus

FES–Ness H200 Hand Rehabilitation System. The Ness H200 Hand Rehabilitation System (H200; Bioness Inc., Valencia, CA) is a NMES system incorporating a wrist extension orthosis and NMES. The H200 is a microprocessor-based, U.S. Food and Drug Administration–approved device that was administered as part of a structured activity program described as follows. It consists of a forearm–hand molded orthosis that contains an array of five surface electrodes ranging in size from 2 × 2 cm to 6 × 4 cm. The electrodes are positioned over the extensor digitorum, extensor pollicis brevis, flexor digitorum superficialis, flexor pollicis longus, and adductor pollicis muscles. Electrode position within the orthosis is custom fit for each patient to optimize the contraction of the digit flexors and extensors. Once the optimal position is determined, the five electrodes are secured within the orthosis. This individualized electrode position enhances the consistency of stimulation with each use. The electrodes are connected to a stimulator that delivers alternating current at a carrier using a sinusoidal, balanced wave form with a frequency of 11 KHz and pulse bursts at 36 Hz ranging from 0.01 to 0.5 mS.

For this study, the stimulator was set in an interrupted pulses mode with the contraction and relaxation intervals set at 6 s ON and 6 s OFF. Two seconds of ramp up and ramp down were included in the 6-s time, resulting in 3 s of sustained tetanic contraction that either flexed or extended the digits.

TR–Computer Camera and Communication Applications. Two Logitech Buddy Cams were used to enable the study's therapist to communicate with the participant online, as described here. Each camera included a built-in microphone and software allowing real-time 640 × 480-pixel video, still-image capture, archiving, editing of videos and images, and other features. The camera weighs <1 lb, can be placed on a tabletop or computer monitor, and plugs into a computer USB port. The camera also easily interacts with free network meeting and instant messaging software. Together, these features allowed the participant and therapist to communicate in real time via the World Wide Web as described here. From our laboratory, a broadband connection (500 k) was used to transmit therapy instructions as described here. However, the participant used dial-up connections (56 k) from his home to connect to the Internet to participate.

Skype is one of many telecommunication tools. It was chosen because it is free, easy-to-use, downloadable software. This software was downloaded from www.skype.com and installed immediately by the participant and therapist. At scheduled meeting times, the two parties met through the Skype program to complete the TR sessions.

Intervention

Initial Fitting and Education Session. Five days after pretesting, the participant returned to the laboratory and met with the treating therapist. The H200 was fitted to the participant, and he was educated on device use during an 1-hr-long education session. He was also provided a PC camera and software and educated on camera use. The participant and therapist determined a schedule in which online therapy sessions would occur. At home, the participant downloaded Skype and installed the PC camera to be used to conduct the TR sessions between the therapist and the participant. On the same day, the therapist administered the COPM to the participant to determine client-centered, occupation-based activities to determine treatment plan goals.

Home Program and TR Sessions. At home during the first week, the participant was instructed to ramp up the stimulation during the first 5 days to acclimatize the body to the stimulation. The stimulation program started at 10 min, with a 5-min increase each day.

For the next 3 weeks, the participant used the H200 at home in 30-min increments. As described here, a portion of these sessions was online and supervised by the therapist, whereas the rest were self-administered by the participant. The protocol frequency and duration were chosen because they were consistent with previous work using this device (Hill Herman et al., 2008). The participant returned the PC camera during his posttesting session.

Supervised, Online Session. Using the Logitech camera and the Skype software, the participant then engaged in individualized, 30-min therapy sessions, occurring two times per week for 3 weeks, all administered by the same therapist. For the sessions, he logged in at the scheduled therapy times, and therapy was administered online using the camera and meeting software. The participant adjusted the camera for the therapist to see his body and the contexts surrounding him. It was important to see both upper extremities during bilateral activities and the torso to provide feedback regarding compensatory techniques used. It was also essential to see the participant's head so that the therapist could interpret facial expressions to help guide treatment. The camera was also adjusted when the participant moved from his desk to allow the therapist to see the context in which he was working (i.e., moving in his office or working at his desk). After the review of participant status and demonstration of H200 management, the therapy concentrated on increasing affected upper-extremity use during ADLs identified by the participant through the COPM. Skills included using a knife and fork for eating, grasping a ball to play with his dog, driving with both hands, and tucking in and buttoning his shirt (Figure 1).

Unsupervised Home Sessions. On the other 3 days of the week, the participant engaged in the identified COPM tasks and functional activities, each for 30 min per day, two times per day. The participant exhibited intermittent swelling in his affected upper extremity; therefore, the therapist also instructed him to complete passive range of motion of fingers and retrograde massage of the forearm and fingers to be able to don the orthosis.

Eating with a knife and fork	Driving with both hands
Grasping a ball	Tucking in his shirt
Playing with the dog	Buttoning his shirt

Figure 1. Purposeful activities used during the telerehabilitation: The participant worked on these tasks during the telerehabilitation session.

Posttesting

One week after therapy completion, the participant returned to the same laboratory at which the pretests were administered. The same evaluators who performed the pretests administered the FM, ARA, and COPM again. The participant also returned the H200, camera, and software.

Results

Per the study protocol, the participant was to stimulate the affected upper extremity for a total of 16 hr, 40 min, in 4 weeks. The H200 compliance feature for this participant reported 9 hr, 20 min, for the total duration of the study. The participant exhibited a gain of 2 points on the FM (25/66 to 27/66), with noted improvements in forearm pronation and supination with his upper extremity in neutral and wrist mobilization and circumduction. He also exhibited a gain of 8 points on the ARA from 10/40 to 18/40. More specifically, his grasp improved for various sized blocks, marbles, and ball bearings (Table 1).

The participant exhibited notable changes on the COPM (Table 2), particularly in his satisfaction of task performance. His satisfaction significantly increased for all five of the COPM tasks by 4 to 6 points. He exhibited notable performance changes in one COPM task.

Functionally, the participant reported that he used both hands to perform many ADLs. He could drive using both hands, go out to eat dinner with friends, and use both hands to manage his utensils. He was able to catch and throw a ball to play ball with his family and dog. He reported feelings of pride when others noticed that he could use his right hand when he was working, out with family, and at parties.

Discussion

Given challenges with both access to conventional rehabilitative care and conventional NMES, this study examined efficacy of an NMES-based neuroprosthesis program administered over the Internet. The therapy was administered using commercially available PC cameras and free networking software. As noted previously, after participation in this regimen, the participant's affected upper-extremity impairment and functional limitation each decreased, and his ability and satisfaction while performing ADLs with the affected upper extremity each increased. These data add to a growing body of evidence suggesting efficacy of NMES using a neuroprosthesis (Alon et al., 2007; Hill Hermann et al., 2008). Although promising telemedicine techniques have been suggested (Heuser, 2007), including in stroke rehabilitation (Hess, 2005; Reinkensmeyer, 2002), many clinics have neither the monies nor the expertise to administer these costly techniques using extensive equipment. Thus, the current findings are also important in that they corroborate a report in which modified constraint-induced therapy (a reimbursable, outpatient version of constraint-induced therapy) was administered entirely by means of the Internet using PC cameras (Page & Levine, 2007). Collectively, these data should be welcome news for therapists who may be working with patients in remote areas or with transportation challenges.

Table 1. Fugl-Meyer (FM) and Action Research Arm (ARA) Results: Score Change Before and After Intervention

	FM			ARA		
	Pre	Post	Change	Pre	Post	Change
Scores	25	27	+2	10	18	+8

Limitations and Future Research

Despite the promise of the protocol, several challenges should be noted. First, neuroprosthesis compliance was a limitation in that the participant sometimes used part of his stimulation time to massage or stretch his hand to better don the orthosis. Moreover, although the neuroprosthesis monitored time that the device was on, it may not have entirely captured time during which the participant was actually participating in therapeutic activities. In the future, it is suggested that participants keep a usage log for time spent stimulating and an activity log for time spent actually performing therapeutic activities. We also suggest that therapists work closer with clients to develop a specific, customized home activities program for using the H200. It is likely that such advanced planning would maximize participants' use of the device and subsequent benefit.

One promising aspect of the study was the participant's ability to use the device independently and to adjust the program on the device under the verbal guidance of an occupational therapist. This facet allowed the participant autonomy in his rehabilitation and may have enhanced participant motivation. We also submit that TR use enabled the participant to engage in occupation in his own environment, which increased carryover of skills. Future researchers should examine carryover and motivation associated with a TR-based protocol versus those that are clinically based so that these hypotheses may be further examined.

A threat to generalized use of this regimen will be the level of computer competency that participants exhibit before starting TR. In this study, the participant regularly used the computer, and this could have affected his ability to engage in TR. For future studies, it is suggested that researchers systematically evaluate technology education and setup time on a more population-based and diverse group of

Table 2. Canadian Occupational Performance Measure Results: Change in Participant Performance and Satisfaction With Selected Tasks Before and After Intervention

	Performance			Satisfaction		
	Pre	Post	Change	Pre	Post	Change
Overall scores	2.4	3.4	+1.0	1.0	6.0	+5.0
Eating				1.0	5.0	+4.0
Holding a ball	1.0	5.0	+4.0	1.0	7.0	+6.0
Driving	2.0	3.0	+1.0	1.0	7.0	+6.0
Tucking in shirt	3.0	3.0	0	1.0	6.0	+5.0
Buttoning	3.0	3.0	0	1.0	5.0	+4.0

patients. Indeed, it is plausible that not all participants will benefit equally from this intervention because of their lack of comfort with computers and technology. In this study, the participant met with the therapist online to ensure that all technical difficulties were addressed before the first TR session, which helped to reduce problems initially. Technical difficulties in this study included reversal of the computer screen picture during several sessions, distracting noises caused by audio feedback, and audio delays. Thus, it is also suggested that technical support services be available to address problems in a systematic manner by means of a standard troubleshooting protocol that may arise during treatment. In this study, technical difficulties did occur; however, they did not disrupt sessions because the participant was highly competent in computer usage and assisted with troubleshooting. Others who face challenges with technology may find more limited therapeutic benefit.

Finally, for future studies it is recommended that therapists work with their institutions to ensure use of a secure network connection. In the clinical setting, use of an unsecured Internet connection without obtaining patient consent violates the Health Insurance Portability and Accountability Act. ▲

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