The recovery of running ability in a patient post traumatic brain injury

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Matthew Frear
Kristin Seaburg
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Approved:

Gabriele Moriello
Gabriele Moriello PT, MS, GCS
Research Advisor

Marjane Selleck PT, DPT, MS, PCS
Marjane Selleck PT, DPT, MS, PCS
Program Director, Doctor of
Physical Therapy Program

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Kristin Mae Seaburg ___ May 2, 2008
Date

Matthew Frear ___ May 2, 2008
Date

Sage Graduate School

Office of the Dean

October 6, 2006

Gabriele Moriello
The Sage Colleges
Department of Physical Therapy
45 Ferry Street
Troy, NY 12180

IRB PROPOSAL # 051-06
Reviewer: Dr. Samuel W. Hill, PhD

Dear Gabriele:

I have completed the review of your project entitled "The effect of partial body weight support training on the ability to run in an adolescent male with a cerebral hemorrhage" and with the clarifications provided, your project has been approved.

Please refer to your IRB Proposal number whenever corresponding with us whether by mail or in person.

When you have completed collecting your data you will need to submit to the IRB Committee; a final report indicating any problems you may have encountered.

The Sage IRB Committee has approved your project for one year from the date of this letter. Should your research extend beyond one year, you must reapply to the Institutional Review Board.

Please let me know if you have any questions

Sincerely,

Samuel Hill

Samuel W. Hill, PhD
Chair, IRB

SWH/rd

Cc: Dr. James Brennan

Abstract

The purpose of this case report was to document outcomes following a strengthening program and treadmill training using body weight support with an adolescent male whose goal was to run again. Case Description: The subject was a 16-year-old male who sustained a cerebral hemorrhage following a skiing accident in January 2003. Upon initial evaluation, he presented with significant left lower extremity weakness, especially at the ankle. He was able to run 40' with supervision wearing a plastic AFO with 90º plantarflexion stop on the left. The participant received strength training once a week for 17 weeks, treadmill training using body weight support once a week for 16 weeks, and then a combination of over ground training and strengthening exercise once a week for 6 weeks. Outcomes: Improvements in bilateral lower extremity strength were noted. The subject is now able to run half mile independently. Observational videotape analysis shows the quality of his running improved with regards to foot, ankle, knee, and hip position, knee control during stance and swing, and weight bearing through the left lower extremity. Discussion: A program consisting of strengthening and treadmill training with body weight support may have promoted the subject's ability to run. The change in his status has allowed him to participate in physical education by running around the track and playing softball with his peers. He now wears a less restrictive carbon fiber AFO as a result of gains in left lower extremity strength.

A Traumatic Brain Injury (TBI) is defined as “a blow to the head or a penetrating head injury that disrupts the normal function of the brain.”[1] Persons considered at highest risk for sustaining a TBI are those between the ages of 15 and 24, and persons over the age of 75.[2-4] The risk of TBI is 70 % greater among males than females due to higher risk taking behaviors.[5] The leading causes of TBI include motor vehicle accidents, acts of violence, sports injuries, and falls.[2, 3] According to the Centers for Disease Control and Prevention, about 5.3 million Americans are classified as having a long-term need, or requiring aid to perform normal activities of daily living as a result of TBI.[4]

Prognosis following TBI is dependent on the type of insult, the extent of neurological damage, the location of insult geographically in the brain, secondary complications following the insult, age of the patient, and prior level of functioning.[4] Traditionally, rehabilitation following TBI has emphasized assessment and treatment of functional limitations. Treatment goals are often specific to functional limitations and not long-term disabilities. Higher levels of function required for social involvement and return to the desired level of quality of life are often not addressed if the patient is able to demonstrate independence in activities of daily living and instrumental activities of daily living. Running is one example of a higher level of movement often excluded from treatments, yet it can be an important part of one’s lifestyle. The inability to run is likely to reduce full participation in social activities like playing with children or involvement in sporting events.[2, 6] In addition, recovery from TBI is compounded by a prolonged period of inactivity often associated with muscle atrophy and weight gain, both detrimental for performing higher levels of movement. Inactivity can result in severe detraining and subsequent reduced physical fitness levels making higher levels of movement more difficult.[4]

Rinne and colleagues[7] used a cross-sectional study to compare the motor performance of 47 physically well-recovered men with TBI with that of healthy men. They reported 79% of men recovering from a TBI had to change their sports activity, 13% had to quit former sports activities, 27% noted they do not exercise weekly, and 58% do not participate in leisure activities more than once per week. When asked why these men had difficulties returning to sports activities, 25% reported it was because they had difficulties running.[7]

Understanding the biomechanics of running is vital when re-training a person's running technique. The act of running requires greater strength, balance, coordination, muscle reflexes, and motor control than the act of walking. The increased demands on the body are related to the increased force; proprioception and sensory input processing; muscle recruitment; velocity; and speed of movement. There are many key components, which differentiate running from walking. Walking includes a smaller stride length, wider base of support, a period of double support, and a center of gravity which is located midline. Running includes a longer stride length, narrow base of support, no period of double support, and a center of gravity which is located more anterior.[8] Running requires a significant larger amount of range of motion, on average, than walking. Ciccoti et al[9] reported that in the sagital plane the approximate arcs of motion are 50° at the ankle, 95° at the knee, and 40° at the hip when running at a slow pace.[9] During walking the greatest arc ranges of motion are 25° at the ankle, 60° at the knee, and 25° at the hip.[10]

Running is comprised of a support phase and a recovery phase. The support phase is analogous to the stance phase in walking. It includes initial contact where elastic energy is stored, midstance, and propulsion where stored energy is released. The recovery phase includes a swing phase, which involves forward swing and foot descent, and a float phase, which is the period of no support. The duration of each phase depends on the speed of running. Generally, the support phase makes up 40%, swing phase makes up 30%, and float phase makes up 30% of the total running phase.[11, 12]

Upper extremity and trunk motions are key components of running biomechanics as well. Without movement above the hips, balance and coordination are compromised. The upper extremity and trunk provide reciprocal movement to produce torque and force as well as provide an equal center of gravity and balance when in the multiple stages of running.[12] Lack of upper extremity and trunk movement also insinuates lack of rhythmic and repetitive movement, which is normally produced with proper mechanics. Abdominal strength, commonly referred to as core strength, is a key component of proper mechanics of running. The abdominals aid in stabilizing the spine, providing proper posture, holding up the trunk and keeping it stable to allow for the extremities to move around the central stability. The neurological concept of proximal stability, provided by the core musculature, allowing for distal mobility in the upper and lower extremities is applicable to the act of running.[13]

Persons with TBI often develop impairments, which interfere with the ability to run. These include increased tone, impaired stretch reflexes, decreased balance, decreased proprioception, decreased sensation, decreased coordination, instability of joints, and cognitive issues. These impairments place the person at higher risk for injury, since running mechanics involve a period of no support and greater phases of single leg support with greater momentum and force applied to the joints. When proprioception is impaired, normal sensory and joint input is lost during the phases of running.[1] Perception and sensory systems are crucial when retraining a movement as they provide information about the location of the body in space, and the changes that occur in the surrounding environment that warrant change. Decreased eccentric and concentric control attributes to poor timing, as muscles are slow to respond accordingly to the phases of running and external feedback. Increased tone results in a subsequent loss of range of motion and controlled voluntary movements required for the different phases of running. Decreased joint stability especially during the running phase of single leg support increases the risk for falls and musculoskeletal injury. Hyperextension is a common joint laxity and muscle deficiency resulting in knee problems in the long term. Cognitive processes are essential to the initiation and maintenance of movement skills and cognitive impairments will interfere with the ability to reproduce learned skills independently.[13]

As therapists it is our responsibility to maintain the wellbeing and safety of clients at all times hence the possible hesitation to include running as part of the plan of care.[3] It is often not feasible to retrain someone with a TBI to run over ground due to risk of injury. One specific method of training which can address running safely is body weight support treadmill training (BWSTT).

BWSTT involves suspending the patient in a parachute like harness, which allows for a percentage of the patient’s weight to be relieved while they are walking or running on the treadmill. The decreased weight in addition to external support has similar effects of a supported pool work out by decreasing body weight externally and allowing less pressure on the joints and systems for increased mobility. Individuals can run on a treadmill in a safe environment where running would be difficult or impossible without such a system. The harness also provides postural control and proximal stability allowing for greater distal mobility. Greater proximal stability facilitates repetitive reciprocal locomotor training to ensure that asymmetries do not develop. BWSTT also increases safety for the therapist as it promotes the use of correct body mechanics. The therapist or therapists can facilitate the patient's body to produce the desired movement without handling a large portion of the client's weight at one time. With their hands free to treat, a therapist can facilitate proper biomechanics at the trunk, or lower extremities while the patient is running on the treadmill. Finch and Barbeau[6] report by using the body weight support system during ambulation, both balance and locomotion are retrained simultaneously rather then the more traditional physical therapy method of separately addressing each deficit.[6]

BWSTT can utilize the stretch reflexes in running. Unlike conventional therapy, BWSTT allows us to safely control the speed of the treadmill, therefore controlling the strength of the reflex. By increasing the speed at which the patient runs, there is an increase in the strength of that reflex. Ross et al[14] suggest that the speed of an impulse transmission along the motor axon may have implications on running, specifically sprinting performance and its relationship to fatigue.[14] They state that nerve conduction velocity has been shown to increase after a period of training, specifically sprint training. This suggests that the stretch reflexes are retainable and modifiable to produce greater forces particularly in the hip flexor and triceps surae muscles. Production of higher motor neuron excitability was reported to produce a more powerful muscle contraction. In patients with TBI the motor neuron excitability is often diminished or damaged due to the mechanism of insult and resulting deficits. This evidence suggests that with practice there can be modifications in not only muscular but neurological impulse transmission and nerve conduction velocity with sprint training.[11]

Motor learning refers to the permanent changes in behavior because of practice or experience.[13] Motor learning requires high repetition and feedback. Feedback can come in the form of internal and external feedback. External feedback from the therapist to the patient comes in the form of hands on, manual feedback as the therapist uses hand placements and stimulates muscle recruitment through physical touch. External verbal feedback can also be provided through verbal cuing. Internal feedback is displayed when something does not feel right within the patient and they self correct the problem to display a more organized motor pattern. Individual patient needs determine the amount and type of feedback most effective for optimal performance. Finding the correct method of feedback is crucial to promote perfect practice and perfection of a new motor sequence for a task.[13]

Motor learning promotes motor reorganization in the cortex of the brain. Normally in persons unaffected by TBI or stroke, organization and reorganization occur on a sub cortical level and a new motor task is automatic and innate in nature.[15] Persons with a TBI require assistance with organization and reorganization of motor tasks in the form of feedback followed by practice of the optimal task component in the correct sequence. With proper organization and practice the long-term application of a motor task will become concrete, and change can be permanent. Through motor learning, the subject is able to improve the sequencing of muscle activation. It is for this reason that task sequencing is practiced multiple times and over long durations of time for optimal long-term results and correct muscle activation in accordance with time and the environment. Motor learning is a process that occurs across hours, days, and weeks.[13]

BWSTT provides the conditions for motor learning. The BWS harness decreased patient weight load and pre-set times and speeds on the treadmill allow for a safe environment to facilitate and practice proper running biomechanics. This repetition is required for long-term results. Progressively decreasing the amount of BWS and increasing the treadmill speed allows the physical therapist to gradually increase the difficulty of the task as the patient's ability improves. BWSTT allows the clinician to have the "hands on" in facilitating and retraining desired motions, a classic example of external feedback.[16] When placed on a treadmill, the patient's pelvis is stabilized by the harness allowing the therapist to focus on required facilitation of movement around the stability provided. Gait patterns can become more symmetrical thus providing a chance to improve motor control and coordination facilitating patient internal feedback for proper patterns.[16, 17]

Specific literature using BWSTT to retrain patients with TBI to run is limited although there are influential articles in the literature to support the basis of its use in running. There has been a variety of studies that have examined the efficacy of BWSTT on gait. Most of this literature in adults has been completed in those diagnosed with a cerebral vascular accident and spinal cord injury and the preliminary findings have been promising. Researchers have determined that subjects demonstrate increased stride length, increased muscular strength, increased neural plasticity, more normal kinematic and kinetic aspects of the gait pattern,[17] better balance, increased walking speed, and increased endurance. The literature in the TBI population is limited and results have been inconsistent.[18] Since the results with walking are promising,[16, 19, 20] we can hypothesize similar results with running.

Millslagle[21] investigated full weight support and body weight support using a kinematics perspective with healthy athletes running on a treadmill at a high constant speed.[21] They found that use of BWSTT to run did produce significant changes in selected kinematic measures, implying it is an effective treatment for injured athletes and for running retraining and analysis.[22]

In a single subject design completed by Miller et al[11] a 38-year-old male diagnosed with CVA was trained to run using BWSTT. The subject received 6 months of monitored therapy 3 times per week for 8 weeks. Each session consisted of 3 bouts of running up to a maximum of 10 minutes. He displayed improvements in sprint speed and timed standing on the left leg when baseline and immediate post-intervention phases were compared as well as improvements in sprint speed, time standing on the left leg, and step width when comparing baseline and the 6-month follow up. The authors concluded that BWSTT is feasible and effective in retraining someone with a TBI to run again.

BWSTT has been evaluated and researched with walking; however research is limited concerning treadmill training using BWS and running. The purpose of this case report was to document outcomes following a strengthening program and treadmill training using body weight support with an adolescent male whose goal was to run again.

Methods

The subject of this case report was a sixteen-year-old male who sustained a traumatic brain injury in 2003 when he fell while skiing. Upon admission to the hospital, he underwent emergency surgery to repair a ruptured blood vessel and was in a coma for six days. According to the family, medical imaging results indicated damage affecting the basal ganglia. Following 4 ½ months of subacute rehabilitation, he was able to walk independently with a crutch household distances and used a wheelchair when out in the community. Over the years he has received constraint induced movement therapy and neuro-developmental treatment in addition to regular physical therapy and occupational therapy interventions. Currently he is receiving occupational therapy using Saeboflex once per week. He has a history of asthma.

The subject's diagnosis falls into preferred practice pattern *5D: Impaired Motor Function and Sensory Integrity Associated with Nonprogressive Disorders of the CNS-Acquired in Adolescence or Adulthood* in The Guide to Physical Therapy Practice.[3] He was chosen for this case report based on his main goal for rehabilitation which was to run one mile, and his level of function prior to the study. He was very motivated, willing to participate and had supportive family who were willing to provide him with a body weight support system in his home as well as assist him with his home exercise program. His parents gave written informed consent and he gave assent to participate in the project. Human subject's approval was obtained from The Sage College's Institutional Review Board.

Examination

The current initial physical therapy evaluation occurred 2 ½ years following the initial injury. The subject was six foot tall and weighed 205 pounds. He was functioning at Level VIII on Ranchos Los Amigos Level of Cognitive Functioning Scale. He reports being nearsighted in his left eye and far sighted his right eye. The subject denied being in any pain. Passive range of motion was within normal limits throughout except for left ankle dorsiflexion which measured 0-5 degrees. He presented with decreased strength of his left lower extremity as compared to his right with large deficits of the hip flexors, hip extensors, knee flexors, knee extensors, ankle plantarflexors and ankle dorsiflexors. See Table 1 for initial strength values.

An increase in extensor tone was noted in the left lower extremity while the right lower extremity tone was normal. See Table 2 for results of Modified Ashworth testing. Light touch and pain/temperature testing of bilateral lower extremities were intact as was position sense and kinesthetic testing. A moderate impairment in coordination was evident in left lower extremity in that his movements were slow, awkward, and unsteady. The subject was able to reach 37 cm during the Functional Reach Test and he scored a 55/56 on the Berg Balance Scale. He was able to stand in a tandem position for 30 seconds with the right foot in front and 10 seconds with the left foot in front. During timed standing on one leg, he was able to stand for 10 seconds on the right leg and 2 seconds on the left leg. With CTSIB testing he was able to maintain positions 1-4 for 30 seconds, position 5 for 1.7 seconds, and position 6 for 7.1 seconds.

The subject was able to ambulate community distances without a device wearing a plastic hinged AFO with a plantarflexion stop on the left, which controlled for ankle instability and foot drop. He was able to run 40 feet with close supervision on even surfaces wearing the AFO. He was independent all ADL's and IADL's using his right arm mostly to accomplish all tasks. He attended high school, drove with adaptive equipment, and participated in school activities like the debate team.

Outcome Measures

The outcome measures criteria chosen for this study were the six-minute walk test, bounding, toe walking, backward step ups, timed standing on one leg, muscle strength of the lower extremities, running distance, and running speed, The six-minute walk test, toe walking, running distance, and running speed were completed on the road outside of subject's house or inside the local YMCA when weather was not permitting. Testing conditions were kept as similar as possible. The other outcome variables were completed indoors. The patient was re-evaluated at two-week intervals throughout the intervention period by a physical therapist with 19 years experience working with this population.

The six-minute walk test was used to measure endurance. The six-minute walk test was chosen over the 2-minute and 12-minute walk tests because it has data on responsiveness/sensitivity to change and is more reflective of requirements of activities of daily living.[23] In addition, the six-minute walk test has been shown to have high inter and intrarater reliability (ICC=0.99) and a good sensitivity to change (SEM%=4.8%) when used to assess walking with patients who have had a stroke.[24] The six-minute walk test has also been found to have an intraclass correlation coefficient of 0.94 and is a valid measure of exercise tolerance and endurance.[25] During testing, the subject was instructed to walk as fast as tolerable for 6 minutes without stopping. It was timed with a stopwatch, and distance was measured in miles using a pedometer.

Four functional motor tasks have been identified as valid predictors in the ability of a person post-TBI to recover the ability to run. For this reason, these four measures were chosen as outcome measures for this case report. The four tasks include bounding forward onto a single leg, walking on toes, backwards step up, and timed standing on one leg.[2] Each of the four tasks was tested twice each reevaluation period and the scores were averaged. All four measures have been shown to have a retest reliability ranging from 0.92-0.97 and demonstrate construct validity in those with TBI.[2]

Bounding forward onto one leg simulates the flight phase of running. This testing procedure has been documented to be completed in the following method. The subject stands on the affected leg with the opposite leg flexed at approximately 90 degrees at the hip and knee. Both hands are positioned behind the back while the person bounds forward onto the affected side.[2] Our subject was unable to maintain a single limb stance on his affected leg long enough to complete this test. The test was modified so that the subject started in a partial tandem stance with the affected leg forward, pushing off with the right leg. In order to be considered bounding, both feet had to come off the floor at the same time, giving him a period of no support. The distance was measured in inches from the point of take-off (toe off) to the point of initial contact (heel strike). The real time judgment of measuring the distances has been found to have an observational reliability with a kappa statistic of 0.71.[2]

Toe walking is a good measure of plantarflexion strength and balance that is required for running.[2] The subject was instructed to walk on the balls of his feet on a flat surface for as long as he could. The subject's heels were closely observed and once one of heels made contact with the floor, the starting and finishing points were marked and measured with a standard tape measure in inches.

Backwards step ups are an indicator of overall lower extremity muscle strength.[2] The subject stood with his back to the stair approximately 8 to 10 inches from the stair. He was then instructed to step back up on the stair with the more affected leg without upper extremity support. As the subject progressed, the height of the step was increased to continually challenge the subject. The height of the step was measured in inches.

Timed standing on one leg is an indicator of the ability to land on one leg during running with proper balance.[2] This task was completed by timing the subject standing on his affected leg with a stopwatch. The physical therapist started timing once the left leg lifted off the floor and stopped timing once his left foot touched the floor. Timed standing on one leg was measured in seconds to the hundredths place.

Muscle strength of the hip extensors, hip abductors, knee flexors, knee extensors, ankle dorsiflexors, and ankle plantarflexors was measured using a Nicholas handheld dynamometer using the protocol recommended by Bohannon.[26] The Nicholas dynamometer has been shown to have good intra-tester reliability (ICC = .74-.94) and gives a reliable measure of muscle torque.[27] It has also be found to have inter-rater generalizability coefficients of G = 0.97-0.98 in measuring muscle torque.[28] In patients with stroke, the Nicholas dynamometer has been shown to have excellent concurrent validity (ICC = 0.94-0.97).[24]

Running distance was measured using a GO walking pedometer by Sportline® and was measured in kilometers. The subject was instructed to run as far he could while wearing the pedometer. Pedometers have been found to be a valid substitute for an accelerometer when measuring distances covered during physical activity.[29] In a 7 day trial of monitoring physical activity, pedometers and accelerometers have been found to have ICC estimates of 0.93.[30] Pedometers have also been found to have reliability coefficients of 0.80 in the measurement of physical activity in both youth and older adult populations.[31]

Running speed was computed after the patient was timed running a marked distance of ten yards. Research studies have used sprinting distances of 80 feet,[32] 40 yards,[33] and 50 yards[34] and have been timed using a stop watch.[35] At the beginning of this case report, the subject could sprint approximately 10 yards. The running speed was thus based on a timed 10-yard sprint and not the longer distances of previous research. As the subject progressed, the timed 10-yard sprint distance remained unchanged for consistency purposes. The subject was instructed to start the timed run on his own readiness. A stopwatch was used to measure the time it took the subject to run the 10 yards. When the subject took his first step over the initial mark, the timer was started and once he crossed the 10-yard mark, the stopwatch was stopped. Time was recorded in seconds to the hundredths place. Two trials of timed running were averaged and speed was determined by dividing the distance by the time.

A videotape of the subject running 10 meters was taken at initial evaluation, discharge, and at follow up 6 months later. The videotape was evaluated by three practicing physical therapist for gait deviations and over all running biomechanics. The first evaluator has a PhD in anthropology, instructs kinesiology, and has practiced physical therapy for 20 years. The second evaluator has doctorate of science in physical therapy, is a geriatric certified specialist, instructs neurological rehabilitation, and has been practicing for 15 years. The third evaluator has a doctorate of physical therapy, is a neurologic certified specialist, and has been practicing for 10 years. The three evaluators were instructed to watch the video tape and complete a list of all biomechanical deviations. These biomechanical deviations were used to assess the subjects overall changes in running quality.

Evaluation/ Prognosis

It was evident that our subject lacked important factors, which are important in running. The subject exhibited a hemiplegic running pattern with an overall deconditioned status. He lacked adequate muscle strength in the left lower extremity. He did not have sufficient hip extensor, knee extensor, and ankle plantarflexor strength nor did he have the endurance to run 1 mile. This lack of strength and endurance would not allow him to propel forward and maintain the propulsion for a constant run. The weakness in his trunk musculature contributed to his lack of balance and stability in weight bearing positions. This decrease in balance and stability decreased his ability to use his lower extremities symmetrically. For 2 years, the subject wore an AFO to compensate for ankle instability and foot drop prevention. The continued use of the AFO changed the biomechanics of his gait in a way, which was not ideal for running. Since the AFO acted as an ankle stabilizer, the subject's own ankle-stabilizing muscles were severely deconditioned and some (the ankle dorsiflexors) showed only trace muscle contractions. The AFO restricted the subject's plantarflexion, which did not allow for a true push-off during toe-off and aided in excessive knee flexion from heel strike to flat foot.

The subject was not physically active since his injury. This compromised his cardiovascular conditioning which is a component that is needed to maintain a distance run. Gait deviations increase energy expenditure makes running less efficient. Hemiplegic gait deviations have been shown to increase the energy expenditure needed for normal walking velocities by 50% to 67%.[36] These impairments had to be addressed in order to regain the ability to run.

The subject's main goal is to be able to run a mile without stopping; speed and time was not of importance. He had good potential to progress towards his goal. He was able to perform 3 of the 4 predictive motor tasks in the ability to run as well as being able to initially run 10 yards. He had normal strength in his right lower extremity, and intact sensation and proprioception bilaterally. He had a history of running before his accident, was young, and had shown a great deal of progress since his injury. He was motivated to improve his performance and had a strong family support system.

Plan of Care

The intervention was divided into three phases. The first and third phases consisted of a running strengthening program which included strengthening of the core and lower extremities, agility, standing balance, proprioception, muscle reeducation, gait training, stretching, and endurance exercises. The second phase consisted of BWSTT. The patient was visited at home by the treating physical therapist once a week for 1 to 1 ½ hour sessions.

Lower extremity and trunk stabilizing (core) muscle strength are important factors in running. Since our subject had a deficit in muscle strength of the left lower extremity, it needed to be addressed before a more functional intervention could take place. Having equal strength in the lower extremities is important for symmetrical running and injury prevention. If the subject started running on the treadmill before an initial strengthening program, the risk of musculoskeletal injury could have been great. The first phase of treatment was designed to increase the strength of his right lower extremity so he could safely meet the demands of treadmill training.

Selection of initial intervention (Phase I)

The initial intervention was designed to focus on the patient's impairments and this period lasted 18 weeks. The patient presented with general deconditioning with a noted weakness of the entire left side of his body. Core stabilization and lower extremities exercises were the main focus during this phase

An initial intervention was developed based on strengthening exercises of bilateral lower extremities Resistance training has been documented to have a significant impact on distance running performance. When placed on a resistance training program improvements in a distance runners VO_2 max, lactate threshold, running economy, anaerobic factors and neuromuscular characteristics have been noted.[37] Since our subject's physical fitness levels was that of a deconditioned athlete, improving muscle performance and endurance was essential before attempting functional activities. The subject did not have the strength to safely complete these activities. Strength training can increase dynamic strength, balance, and proprioception through neural adaptation, thus better preparing our subject for the functional activity of running.[37] Patient completed a six- minute walk that acted as a warm up before exercise prior to all interventions. To maximize limb activation and joint stability, closed kinetic chain exercises were completed.[38] These exercises allowed the patient to use his body weight as resistance while training the stabilizing muscles to maintain joint stability. Examples of these exercises include wall squats,[39] forward, backward, and sideway step ups on a 6 inch step, and single leg stance activities.[40]

An initial home exercise program was developed using these exercise that were to be completed twice a week for two sets of ten repetitions. Patient completed bilateral straight leg raises in all directions in standing using a green theraband. The standing straight leg raises was chosen to increase the patient's balance and stability of the weight bearing extremity while performing the exercise with the other leg. These exercises also increased the strength of the opposite lower extremity since that leg balanced his body weight. The subject completed partner stretches including hamstring, hip flexor/knee extensor, and calf stretches at the end of each treatment session.

Modification of intervention (Phase I)

Unfortunately, the patients fractured his left wrist two weeks into this intervention period, which required modification of his plan of care to avoid use of his left upper extremity. As the first phase of the intervention progress, advancements to the exercises were made once the exercises were completed with ease or when the patient felt comfortable and willing to do more. He completed balance/proprioception training on an airex pad including double and single leg stance with and without eyes open, double and single leg stance while catching a ball, double and single leg stance while reaching for a ball, and hip lifts while keeping feet on airex pad. Core exercises were included while the subject sat on a stability ball with knee extensions, pelvic tilts, knee lifts, reverse plank with shoulders on the ball and knees bent to 90 degrees, hip extensions with chest on the ball. The subject completed strength and balance exercise including, sets of quicksteps, dynamic lunges, and side to side dips.[41]

Lower extremity strengthening exercises included ankle pumps while standing on a foam roller. This exercise was designed to address the subject's plantarflexion strength concentrically, dorsiflexion strength eccentrically, and overall ankle stability. The subject stood on a foam roller while holding on to a wall and complete heel raises. The subject also completed hamstring kicks with a 6-pound medicine ball, which was designed to address hamstring strength. With the subject in prone, a medicine ball was rolled down his legs towards his heels. Once he felt the medicine ball approach his heels, he would lift the ball by flexing his knees at the same time.

Four weeks into the intervention program, left ankle dorsiflexion had not improved so additional attention was focused on improvement. The subject was instructed in mental practice exercises as part of his HEP. The patient was instructed to picture himself moving his foot and toes towards his head without actually moving the foot and toes. Mental practice has been show increase the neural adaptation process by recruiting and increased number of motor nerves to the given muscle group. Cortical reorganization has also has been documented as a result of these mental practice drills.[42]

At week seven, the subject's strength and motor control progressed to the point where more challenging exercise protocol was warranted and plyometric t-test and latter exercises and running drills were introduced. Plyometric exercises are designed to improve the explosive power of a patients' performance. These drills usually include fast pace starting, stopping and changing directions.[43] Plyometric drills can improve the patients' agility by re-enforcing motor programming through neuromuscular conditioning and neural adaptation.[43] By improving agility, the patient would develop better control over his body position while moving through each phase of the running cycle.[43] The t-test consisted of 4 cones, which were place in a square 10 meters apart. The subject started in the middle and was instructed to run to a specific cone that was designated by the physical therapist. Once the patient reached the previous cone, a different cone would be called out at random. Brown and Ferrigno[44] use latter drills to increase agility and speed in athletes. The latter exercises consisted of a chalk drawn latter with 6-8 rungs placed on the floor.[44] The subject was instructed to run through the latter in various patterns including running forward, backward, sideways, on a diagonal, lunges, and quick steps.[44] Initially, these drills proved very difficult for the subject to complete but with training, the subject was able to complete the activities and progress.

A theraband taping technique was developed as an alternative method of preventing foot drop and providing medial lateral stability with exercise and running without the bulkiness and restrictiveness of an AFO. This technique was utilized throughout the intervention since it allowed facilitation of ankle dorsiflexion while still allowing plantarflexion to improve push off torque and provided medial/ lateral ankle stability. The subject's ankle was taped using standard white athletic tape for medial lateral stability using heel locks.[45] A strip of blue theraband was anchored to the dorsal surface of the metatarsal heads and above the heads of the gastroc muscle with white elastic tape. The theraband was the slightly stretched, pulling the ankle into dorsiflexion. An ace wrap was wrapped around the ankle and theraband to aid in medial lateral support and to hold down the theraband so it did not rub or get caught on our subject's shoe. While this technique worked well for ankle dorsiflexion support, the subject's ankle began to supinate during running. The ace wrap application was adjusted so that it was applied in a direction that pulled the subjects ankle into pronation, which provided enough support to prevent the subject's ankle from supinating while running.

Body Weight Support Intervention (Phase II)

At the completion of phase I of this study, the subjects' impairments were improved to the point where he could safely begin BWSTT safely with the goal to improve running biomechanics, speed, and endurance. Training was provided using the Lite Gait System I 250 and lasted 16 weeks. The subject was strapped into a harness with the lower straps placed at the level of the greater trochanter. Initially, groin straps were applied to prevent the harness from sliding superiorly but they proved to be uncomfortable for the patient as they caused friction in the groin area. Leg straps were then substituted for the groin straps and they were attached around the distal thigh instead of the around the groin. The subject found the leg straps much more comfortable and was able to run with better biomechanics.

The subject ran at a self-selected speed at which he was most comfortable and verbally reported when to increase or decrease the speed. The amount of unweighting was determined by the subject. During the first trial with the BWSTT, the subject was comfortable being unweighted 30% of his body weight but as he progressed through the treatments, he preferred full weighting and used the harness mainly as a safety measure. Heart rate, blood pressure, and oxygen saturation were monitored and recorded in the pre run period, during recovery periods, and during post run period. The taping technique described above was utilized while running on the treadmill.

The subject warmed up by walking five minutes on the treadmill at a low speed (2.5-4.0 mph). Following the warm up, the intervention was set up in two to three different running periods in one session. Timed trial running and time-to-exhaustion running are commonly used to assess running endurance preformance.[46] The first period was a timed trial that was designed for speed. He was instructed to run as fast as he could tolerate while running with proper body mechanics and maintain that run with a target time that changed as he progressed. Facilitation and verbal cuing were provided by the physical therapist to prevent retraction of the left hip. Once the subject reported any fatigue or showed signs of improper running mechanics, the speed was decreased to the warm up range of 1.0-3.0 mph for a recovery period. Occasionally the increase in activity would result in wheezing due to his asthma, which decreased his ability to tolerate running.

The second running period was a time-to-exhaustion and was designed for running distance. The subject was instructed to run as long as possible at a comfortable speed. Once again, the subject had complete control over the speed and time. If his running mechanics began to falter, treadmill speed was decreased. If able, he completed a third running period to accomplish the same goal as the second period. Following the intervention, a warm down was completed by walking on the treadmill at 3.0-4.0 mph for least five minutes and then the speed was slowly decreased until finally stopping.

Carry Over training (Phase III)

The third phase of this study was an extended modification of the initial intervention and was designed to carry over the gains from the treadmill training over ground. The use of BWSTT was used to improve the subjects running capacity and running biomechanics. Treadmill running has been stated to be monotonously repetitive with consistent body mechanics while over ground running exhibits frequent changes in speed and body mechanics.[47] The subject improved both his running capacity and running mechanics while using the BWSTT. These gains in repetitive proper running mechanics needed to be applied to over ground running. At the start of the third phase of treatment, the subject was at a higher level of function than when we started the first phase and he could safely carry out an intervention that was functionally based. These exercises focused primarily on running mechanics and running endurance and introduced dynamic stretches. The patient continued to complete latter, sprint, and plyometric exercises during this phase, which lasted 6 weeks.

The intervention started off with a warm up and stretching exercises. The warm up consisted of high knees, gluteal kicks, grapevine, side steps, and high kicks.[48] Dynamic stretches focused on the gluteal, hamstring, and quadriceps muscles in the standing position.[48] A complex and dynamic warm-up has been shown to improve the neuromuscular system by enhancing muscle activation which can lead to better performance in training.[49] The functionally based exercises included a clock exercise, bounding exercise and stretch matrix exercise.[41] Following these exercises, the subject was instructed to run outdoors as far as he could and the session finished with self-stretching.

Outcomes

Upon completion of all three phases, improvements were noted in multiple areas. The subject showed a 23% improvement from initial evaluation to discharge on the six-minute walk test; bounding increased 43% from initial evaluation to discharge; toe walking improved 17323% from initial evaluation to discharge; backwards step up increased 67% from initial evaluation to discharge; and timed standing on one leg increased 3% from initial evaluation to discharge. See Figures 1-5 for specific measurements at initial evaluation, discharge and each re-evaluation period.

Lower extremity strength on the right increased in a range from -20% to 97% from initial evaluation to discharge. Lower extremity strength on the left increased in a range from 1% to 1250%. Refer to Table 3 for specific percent changes from initial evaluation to discharge per muscle group. See Figures 6-11 for specific strength measurements at initial evaluation, discharge, and each re-evaluation period. The improvements in muscle strength were generally greater on the left side when compared to the right leg. Strength measurements were much more symmetrical between the right and left legs as compared to the initial evaluation. Refer to Figure 12 for specific percent differences between the right and left lower extremities.

Running speed improved from initial evaluation to discharge by 682% while running distance improved by 614%. See Figures 13-14 for specific measurements at initial evaluation, discharge and each re-evaluation period. During the last evaluation session the subject was able to independently run 0.67 of a mile and he reported the ability to independently run one mile in school by the time of discharge. He was also able to progress to wearing a carbon fiber brace.

ICC values for test-retest reliability were >0.70 for bounding, hip abductor strength, knee flexor strength, ankle dorsiflexion strength and ankle plantar flexion strength, and toe walking suggesting above satisfactory reliability for these measures. Reliability was less than satisfactory for one legged stance, knee ext strength, and hip ext strength as the ICC values for test-retest reliability were <0.70.[50]

Initial running analysis as reported by all three specialists during the videotape analysis at discharge revealed left ankle inversion throughout the cycle, decreased trunk rotation, decreased weight bearing on the left lower extremity, vaulting, hyperextension of the left knee, and decreased push-off on the left lower extremity. Improvements from initial evaluation to discharge as reported by the three specialists included better push off, more efficient terminal stance, improved symmetrical weight bearing, improved trunk extension, decreased inversion of the left ankle, and a marked improvement in the left knee and ankle position with a decrease in hyperextension.

The subject was contacted for a follow up 6 months after discharge. Videotape analysis taken at 6 month follow up showed that the subjects running pattern continued to improve with better push off on the left. Follow up testing at 6 months indicate that the subject lost between 5-31% of muscle strength of the left lower extremity since discharge and 12-24% of muscle strength of the right lower extremity. See Figure 15 for individual percentages.

Discussion

The purpose of this case report was to document the use of an over ground physical therapy rehabilitation program and the use of a BWSTT program in the recovery of the ability to run in an adolescent male post TBI. Rehabilitation clinicians are using BWSTT to improve the ability to ambulate in patient populations with neurological impairments.[51] While ambulation is important in day-to-day function, the ability to run can provide an adolescent male with many life-changing possibilities. Our observations demonstrate that the use of a over ground physical therapy rehabilitation program along with the use of a BWSTT program can improve the muscle strength, running endurance, and running quality of an adolescent male post TBI.

The subject demonstrated improvements in all lower extremity musculature except right hip abductors, right ankle dorsiflexors, and right ankle plantarflexors. The major improvements were noted in bilateral hip extensors, bilateral knee extensors, and left ankle plantarflexors which are the main muscles that propel the body during running.[52] By discharge, strength measure in these muscles were much more symmetrical between the right and left lower extremities. These increases in muscle strength coincide with the exercises that the subject executed in the intervention period. During the first phase of treatment the subject began with core stability exercises that focused on the trunk and pelvic strength as well as open chain and close chain exercises of the lower extremity. As the treatment phases progressed through the BWSTT and over ground training, the subject was executing either dynamic plyometric drills or running drills. The force production required to execute the task of running is derived from the lower extremity extensor muscles.[52] The hip extensors, knee extensors, and ankle plantarflexors were extensively trained over the course of this intervention; therefore a large gain in muscle strength and symmetry was expected.

The subjects' left knee flexion and left ankle dorsiflexion values did improve but knee flexion did not achieve the same symmetry between the right and left legs as the lower extremity extensors. As previously stated, the type of training the subject executed did not allow the knee flexors and ankle dorsiflexors to be trained as extensively.[53] Therefore, large gains in muscle strength were not as expected in the lower extremity flexors. It is possible that ankle dorsiflexor symmetry showed as large gains as the extensors due to the addition of mental practice exercises in Phase I.

Our results are consistent with that of Miller et als[11] in that lower extremity strength improved although the percent improvement was greater in this case report. The greater strength improvements may be the result of our three phases of treatment with a strong focus on strength training during the initial phase.

In this case report, test-retest reliability for hand held dynamometry testing of hip abductors, knee flexors, ankle dorsiflexors, and ankle plantarflexors were satisfactory (ICC>.70). However, the ICC values for test-retest reliability for hip and knee extensors were less than 0.70. In the literature, the handheld dynamometer has been shown to have good inter and intra rater reliability, but the quality of the dynamometry measurement is dependent on the subjects' position and the stability of the dynamometer during the test. The subject's positions during evaluations were consistent with Bohannon's recommendations but it is possible that the evaluator's ability to provide enough counter pressure during the test for hip and knee extension was not sufficient. Bohannon states that the stabilization and meeting muscle force production may be particularly difficult for clinicians who are not physically strong. Even though the evaluator was a middle aged female with good overall strength, the evaluator had to be stabilized so she could stabilize the dynamometer to stop from sliding. Once the evaluator was stabilized, the dynamometer shook significantly when the subject's maximal force was given. This indicates that the evaluator's overall strength was not strong enough to provide the necessary counter pressure. This inconsistency in stabilization could have affected the results. Since the strength gains were so large in this case report, the lack of stabilization may not have had a significant effect.

The subject's improvement in his ability to run can be supported by both neuromuscular and cardiopulmonary development. Neuromuscular strength gains have been linked to improve running endurance in athletes.[37] Neural adaptations, increased myofiber size, and contractile elements are documented benefits of resistance training on endurance performance.[54] During the first phase of treatment, the main focus was to improve neuromuscular strength and control via body weight resistive exercise since he was globally deconditioned and presented with left side neuromuscular weakness. The strength outcome values support the fact that his strength improved and more importantly became more balanced with his non-affected side. After the first phase of treatment, these improvements allowed him to begin more task specific training. During the BWSTT phase, the subject was provided with an environment where his cardiopulmonary deconditioning, gait deviations, and motor learning of the running task could be addressed. The BWSTT provided a safe environment in which the subject was in control of the training sessions and could complete an aerobic training session. After the first few sessions, the subject did not like the feeling of being un-weighted so the harness was mainly used as a safety measure in case of a trip or fall. This safety gave the subject the confidence to run at speeds in which he would not feel safe over the ground. Running at higher speeds for longer distances allowed the subject to challenge and improve his cardiopulmonary system.

Recovery of function and compensation for a function are ways in which someone with a deficit can improve their motor control. Recovery has been described as regaining a function that was previously lost while compensation has been described as a behavioral substitution.[13] When observing the changes in the quality of the subject's running, it appears he recovered the function of running, and did not developed compensations. As previously stated, the BWSTT allowed the subject to run at speeds at which he would not feel safer over ground. The faster he ran on the treadmill, the more symmetrical his lower extremities became and the less he was able to compensate. In patients' post stroke, treadmill training has been shown to increase gait symmetry and improve quality of ambulation.[55] The BWSTT allowed the subject to train in a biomechanically beneficial capacity for long periods of time. The video analysis of initial running to running at discharge provided evidence of better push off, increased running symmetry of the lower extremities, and a more efficient terminal stance. As the biomechanics of the subjects running improve the compensatory strategies decreased and the efficiency of his running improved. These changes were maintained 6 months later, which provides evidence that motor learning occurred.

One limitation of the videotape analysis is that the subject's running was evaluated while wearing a plastic hinged AFO with a plantarflexion stop. At the time of the initial evaluation, the subject showed little if no ankle stability and required use of the AFO to prevent risk of injury. While providing ankle and knee stability, the use of an AFO will impart gait deviations. Proper ankle plantarflexion and knee extension during the push off phase of running is inhibited when wearing an AFO and this restriction of natural running mechanics provided observable running deviations. During the third phase of the study, the subjects' plantarflexor and knee extensor strength improved to the point where he was able to upgrade his brace to a carbon fiber spring leaf orthotic that was more suitable for running. While wearing the brace, the subjects' ankle plantarflexion and knee extension became more symmetrical bilaterally thus improving the overall running quality.

The subjects running velocity improved on the BWSTT but did not seem to carryover onto over ground training as indicated in the re-evaluation results. At the beginning of the second phase of treatment using BWSTT the subject's maximal running velocity on the treadmill was 4.0 mph. As the BWSTT treatments progressed, the subject's maximal running velocity improved to 7.0 mph which he was able to maintain for over 30 seconds. This suggests that the subjects running velocity improved which is consistent with Miller et al.[11] However, during the biweekly re-evaluations when running velocity was measured over ground via a timed 10-meter sprint no improvement in running velocity was noted after the fourth re-evaluation session, which occurred during Phase I. One explanation for this discrepancy is that a modified taping procedure which allowed for more normal foot and ankle movement was utilized during treadmill training but during the over ground re-evaluation the AFO was utilized. Running velocity is typically dependent on a person's stride length and stride frequency.[56] The subject wore an AFO during the over ground evaluations which most likely disrupted his natural running mechanics and effectively decreased his stride length and stride frequency and could be a factor why his running velocities did not improve during the evaluations. During the first phase of treatment the subject was required to use the AFO during the running velocity testing because he did not have the ankle stability to run over ground without use of an AFO. For purpose of consistency, the running velocity reevaluations were completed using the AFO.

The method used to quantify the running speed may have measured the subject's acceleration and not his maximal running speed. The distance that was used to measure the subjects running velocity was 10 meters which may have been too short for the subject to reach maximal velocity. In a study completed by Zafeiridis et al[58], un-resisted sprint trained males running velocities were measured from 0-50 meters with measuring intervals of 0-10 m, 10-20 m, 20-40 m, and 40-50 m.[57] The maximum running velocities were observed from 20-50 meters. Running accelerations were observed from 0-20 m. Delecluse[58] reported the acceleration phase of running to be 0-10 meters, a transition phase, and then the maximal velocity phase from 36-100 meters in a 100 meter sprint. This research suggests that what was measured in our subjects' 10 meter sprint was his acceleration, not his maximal running speed. Future research should use distances between 40-50 meters to observe maximal running speed. In addition running speed was measured using a stopwatch and human error can be significant with this method. The most popular way to assess running velocity in the literature is by use of photocells which use small lights that activate and deactivate a timer.[59] This method is more expensive and requires a more stationary environment to be used and was not feasible to use in the current situation since the place of reevaluations changed frequently due to scheduling conflicts or weather.

The main focus of this case report was to improve the running ability of our subject and it revolved around improvements made in the trunk and lower extremities. This case study directed little to no focus to the upper extremity movement and contributions to running because he fractured his wrist. The upper extremity swing helps to provide counter rotation of the trunk from the legs and to drive the legs forward during running.[60] The subject had decreased muscle tone and muscle function in left upper extremity. When running, he held his left arm with his right arm for stabilization, which prevented the left arm from swinging freely. This body position did not allow for proper trunk rotation, and did not allow for the correct arm swing during running. In a sense, this study only addressed half the body. By disrupting the natural and needed arm swing during running, it is possible that he required higher energy expenditure while his speed and distance was lower. With improper arm swing, he was working harder to run while not running as fast or as far as he could have. Future research should take the upper extremity biomechanics into consideration when looking at people with TBI and the ability to run.

The subject did not show large improvements in the timed standing on one leg. The lack of improvement could be a result of the subject's ankle instability. Even though his ankle stability did improve over the course of the intervention to the point where he was ambulating around the house without an AFO at times, it did not improve enough to ambulate consistently without the support of an external device. As previously state, the reliance on an AFO for ankle stability and foot drop can lead to atrophy of the muscles acting as ankle stabilizers which could affect his ability to balance on his affected leg. As the case study progressed, our subject's ankle stability and one-legged stance time did improve, but not in the large quantities that the other predicting tasks did. When running, the subject always had either an ankle brace or his ankle taped to provide stability. Since the focus of this case report was gaining the ability to run, the subject's ankle stability was controlled by external devices.

Improvements in quality of life were not explicitly measured in this case report although anecdotal improvements in his quality of life were noted. The subject first started to notice a physical difference in the way he felt and looked and that he felt "stronger." Changes were also noticed in his willingness to try higher-level activities. Initially, he would balk at attempting higher-level activities but as the intervention progressed, he became more willing and even excited to try more demanding exercise. He would even just break out into a sprint once in awhile just because he could. His improved attitude appeared to carry over into his social life. He was able to play baseball and run the mile with his peers during physical education class. Previous to this intervention, he would swing the bat but another student had to be the designated runner. Previous to this study, our subject would have to complete different activities on the side of the track while the rest of his class ran the mile. The ability to run gave our subject the ability to participate in sport and compete with his peers. A study completed by Morton and Wehman[61] provided evidence that people who sustain a TBI have difficulty maintaining friendships, social supports, and participating in leisure activities. This lack of social contact and support can lead to prolonged loneliness. In terms of leisure activity and sport, our subject was isolated from the rest of his peers.

The subjects’ enhanced outlook on life was also observed by his own family. At the completion of the study, his mother stated. "This effort has made a significant impact on his abilities to feel more positive about himself and his capabilities and to be able to move more into living his life."

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Table 1. Initial Dynamometer Strength Values (kg)			
		Right	Left
Hip	Flexion	18	8.1
	Extension	20	10
	Abduction	16.6	10.1
Knee	Flexion	17.6	0.4
	Extension	18.6	12.5
Ankle	Dorsiflexion	9.1	0
	Plantarflexion	21.5	8.3

Table 2. Modified Ashworth Scale			
		Right	Left
Hip	Flexion	0	0
	Extension	0	1
	Abduction	0	0
	Adduction	0	1
	Internal Rotation	0	1
	External Rotation	0	0
Knee	Flexion	0	0
	Extension	0	1
Ankle	Dorsiflexion	0	0
	Plantarflexion	0	1

Table 3. Percent Change of Lower Extremity Strength from Initial Evaluation to Discharge.			
		Right	Left
Hip	Extension	54%	120%
	Abduction	-20%	1%
Knee	Flexion	97%	1250%
	Extension	97%	86%
Ankle	Dorsiflexion	89%	490%
	Plantarflexion	-10%	57%

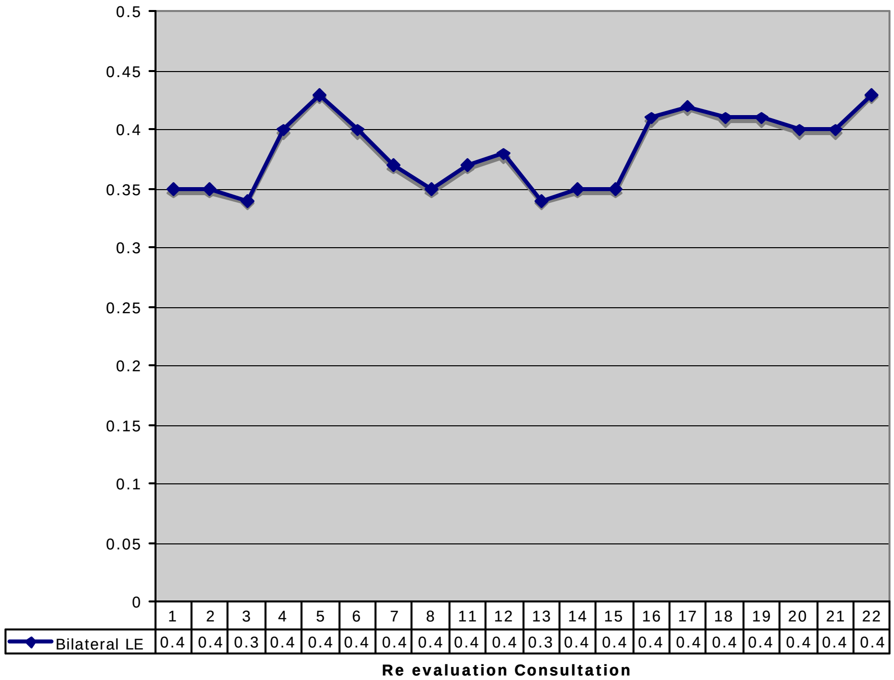


Figure 1. Changes over time for the six minute walk test at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.

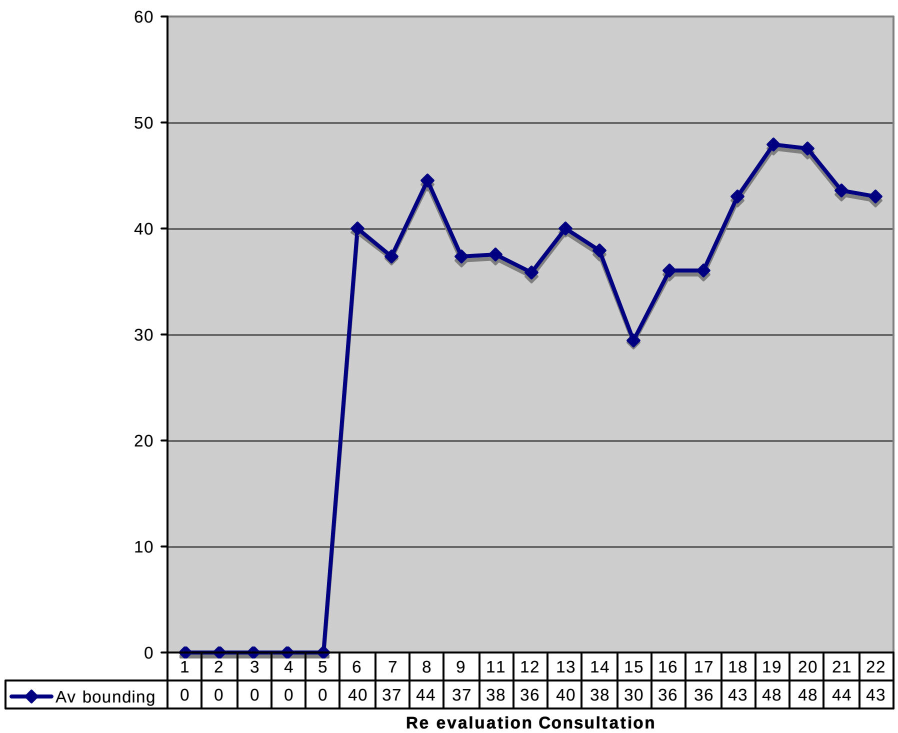


Figure 2. Changes over time for bounding at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.

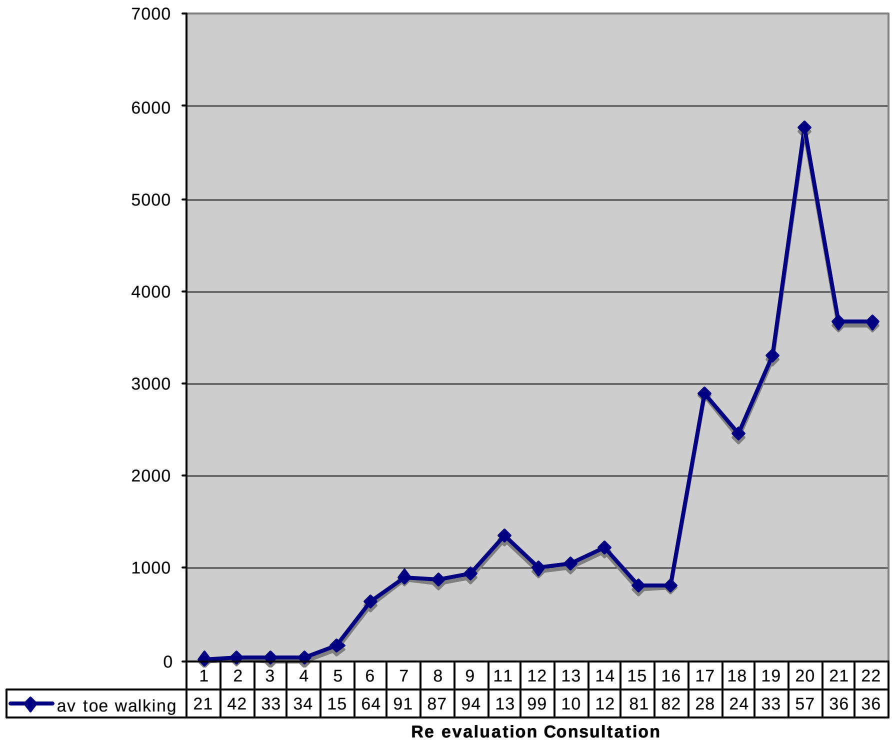


Figure 3. Changes over time for toe walking at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.

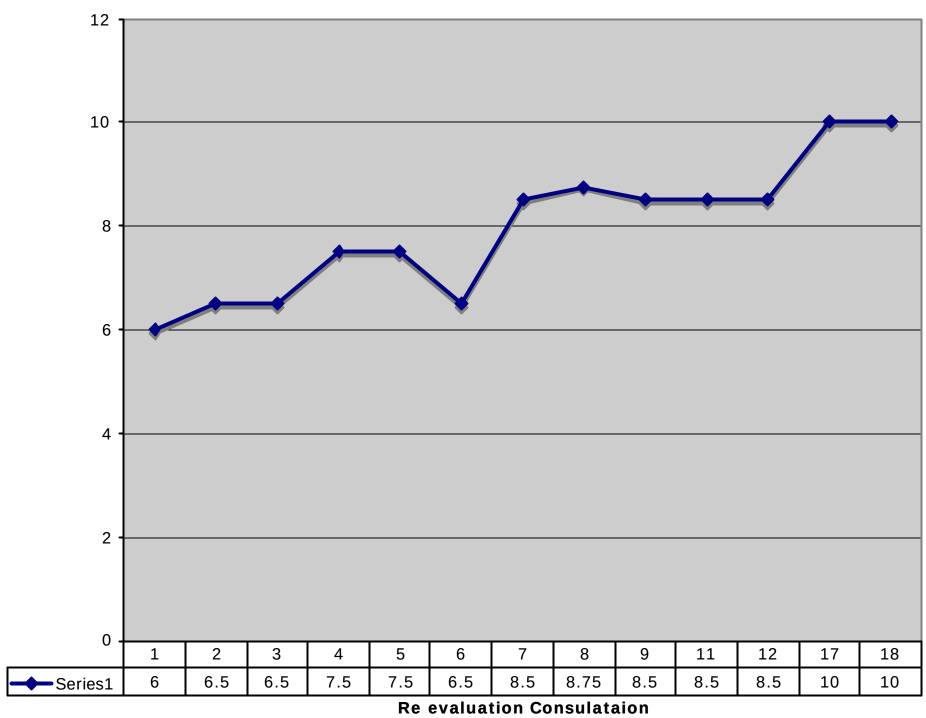
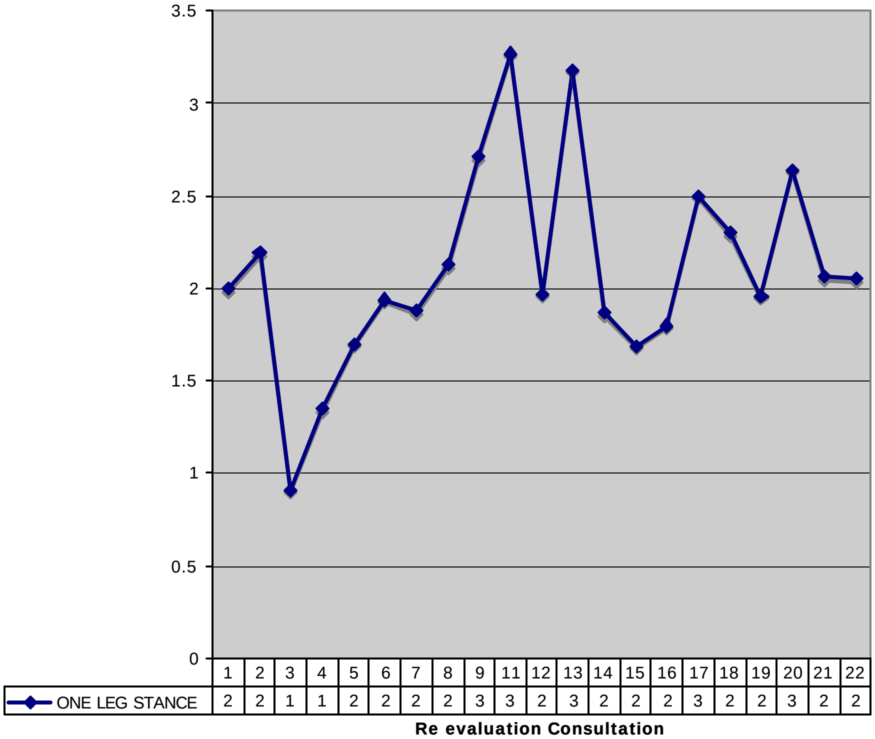
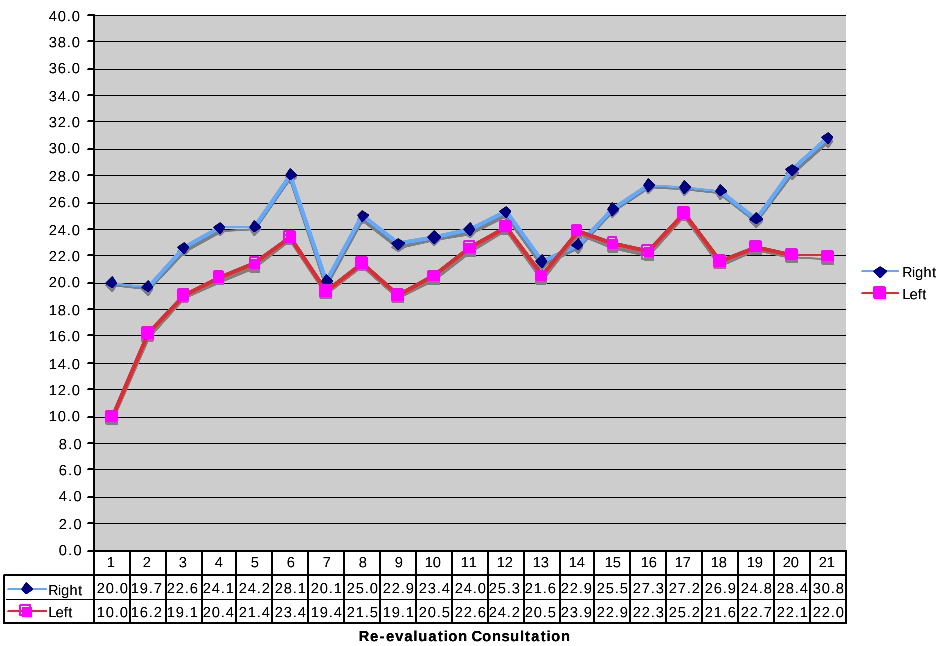


Figure 4. Changes over time for backwards step up at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



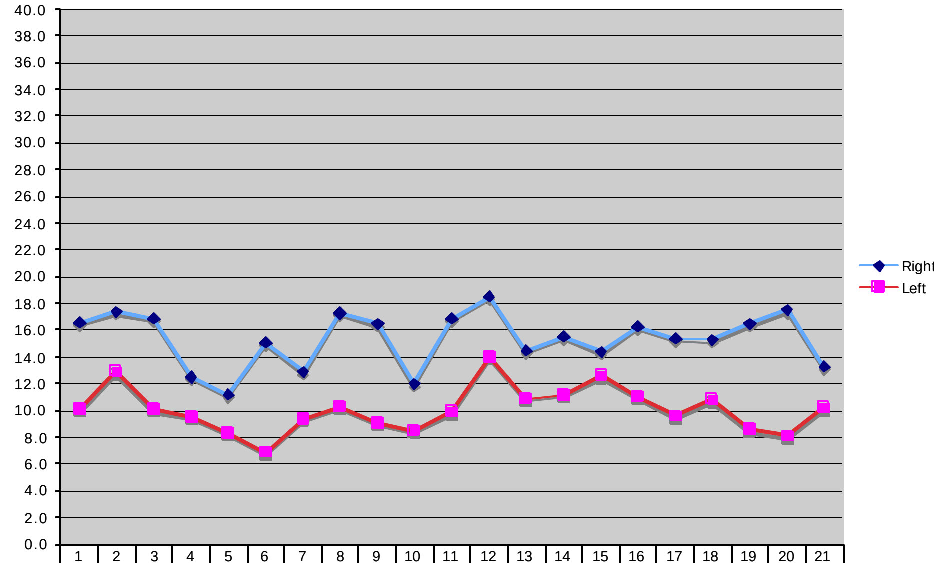
	1	2	3	4	5	6	7	8	9	11	12	13	14	15	16	17	18	19	20	21	22
ONE LEG STANCE	2	2	1	1	2	2	2	2	3	3	2	3	2	2	2	3	2	2	3	2	2

Figure 5. Changes over time for timed standing on one leg at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Right	20.0	19.7	22.6	24.1	24.2	28.1	20.1	25.0	22.9	23.4	24.0	25.3	21.6	22.9	25.5	27.3	27.2	26.9	24.8	28.4	30.8
Left	10.0	16.2	19.1	20.4	21.4	23.4	19.4	21.5	19.1	20.5	22.6	24.2	20.5	23.9	22.9	22.3	25.2	21.6	22.7	22.1	22.0

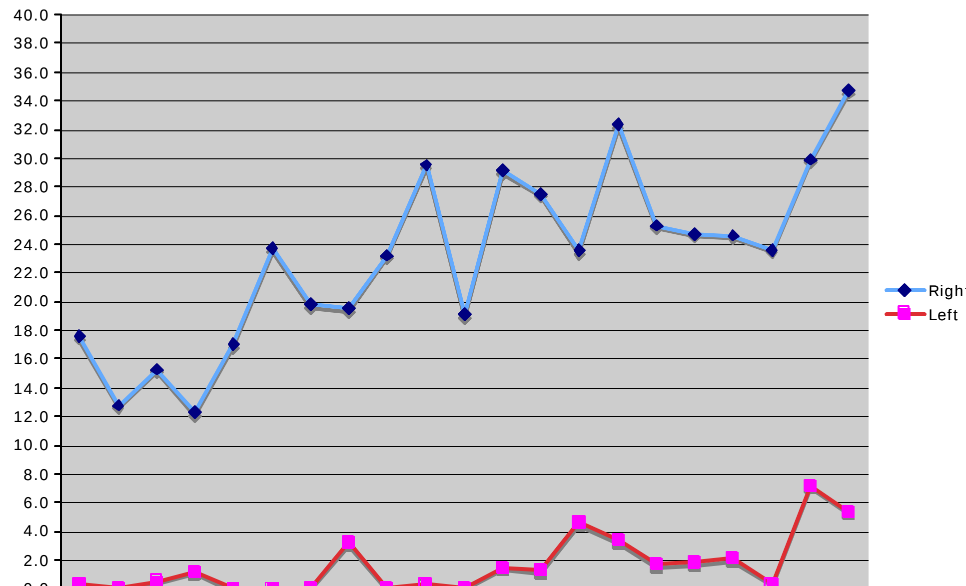
Figure 6. Changes over time in right and left hip extensor strength at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Right	16.6	17.4	16.9	12.5	11.2	15.1	12.9	17.3	16.5	12.0	16.9	18.5	14.5	15.6	14.4	16.3	15.4	15.3	16.5	17.5	13.3
Left	10.1	12.9	10.1	9.5	8.3	6.9	9.4	10.3	9.1	8.5	9.9	14.0	10.9	11.2	12.6	11.1	9.6	10.8	8.6	8.1	10.2

Re-evaluation Consultation

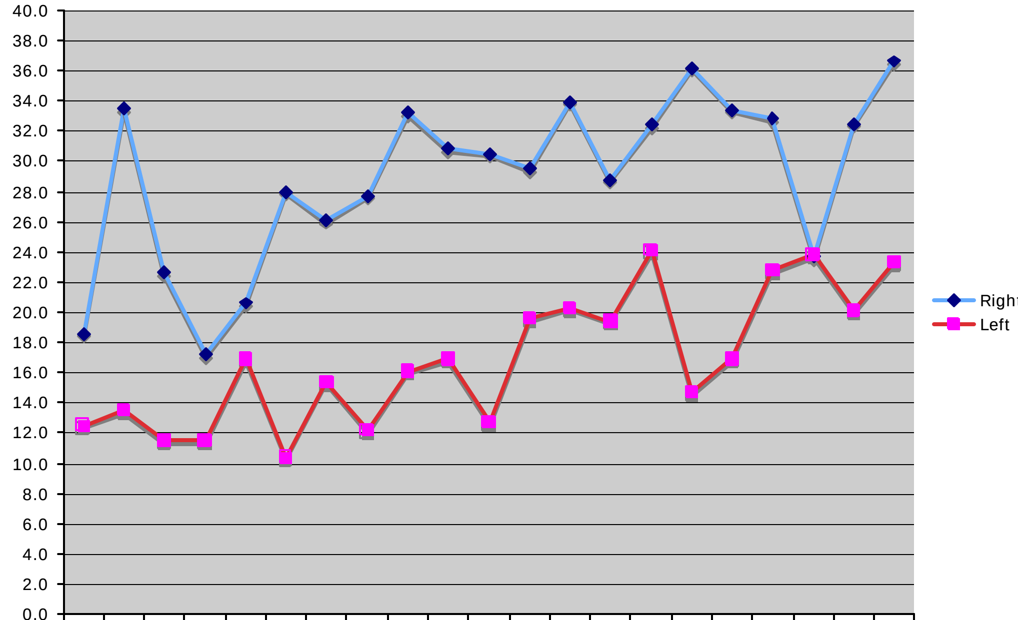
Figure 7. Changes over time in right and left hip abductor strength at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Right	17.6	12.8	15.3	12.3	17.0	23.7	19.8	19.5	23.2	29.5	19.1	29.1	27.5	23.6	32.3	25.3	24.7	24.6	23.6	29.9	34.7
Left	0.4	0.1	0.6	1.2	0.0	0.0	0.1	3.2	0.1	0.4	0.1	1.5	1.3	4.6	3.4	1.7	1.8	2.1	0.4	7.2	5.4

Re-evaluation Consultatio

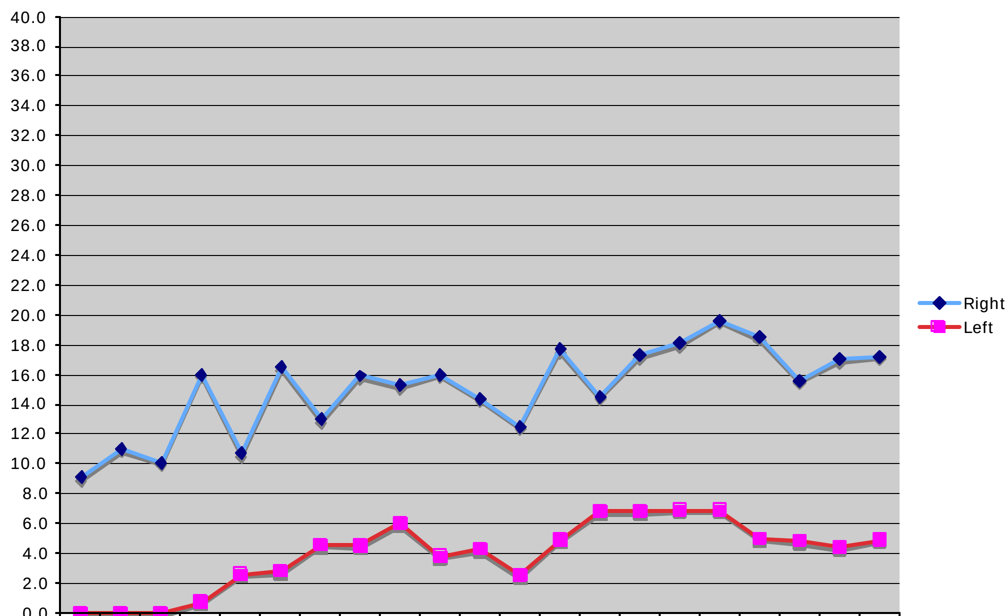
Figure 8. Changes over time in right and left knee flexion strength at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Right	18.6	33.5	22.6	17.2	20.6	28.0	26.1	27.7	33.2	30.8	30.5	29.5	33.9	28.8	32.4	36.2	33.4	32.8	23.7	32.5	36.6
Left	12.5	13.5	11.5	11.5	16.9	10.4	15.4	12.2	16.1	16.9	12.7	19.6	20.3	19.4	24.1	14.7	16.9	22.8	23.8	20.1	23.3

Re-evaluation Consultation

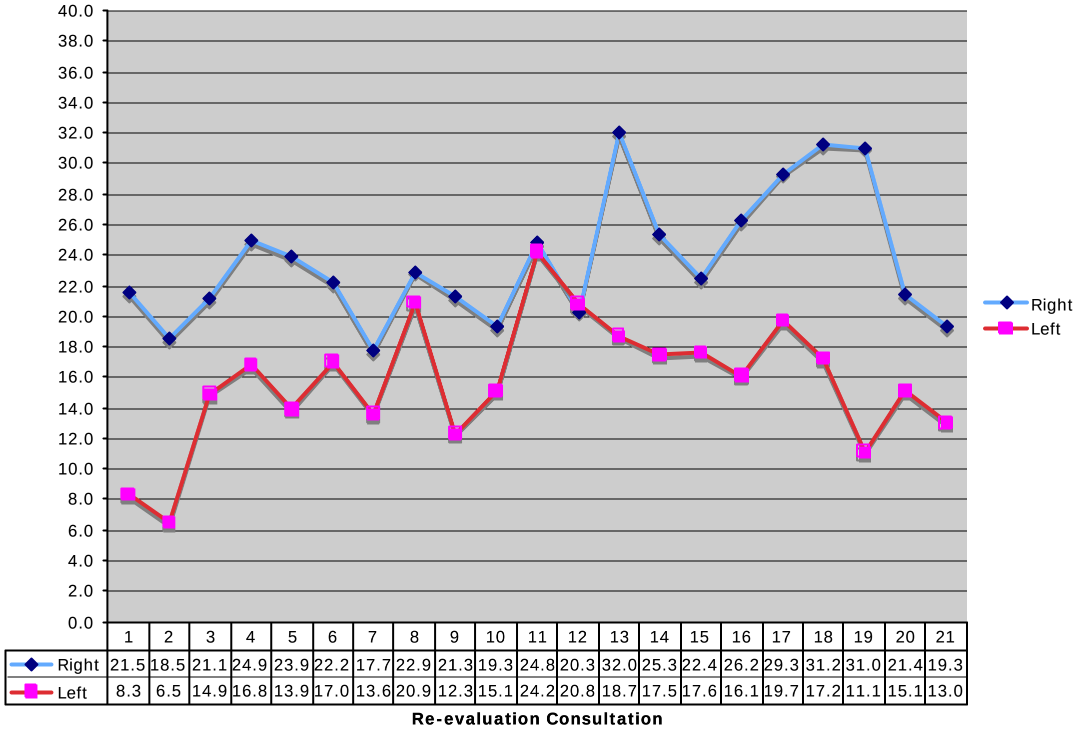
Figure 9. Changes over time in right and left knee extension strength at two-week re-evaluation intervals between admission and discharge consultation of a patient 17-year-old-male subject with a TBI.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Right	9.1	11.0	10.1	16.0	10.7	16.5	13.0	15.9	15.3	16.0	14.4	12.5	17.7	14.5	17.3	18.1	19.6	18.5	15.6	17.0	17.2
Left	0.0	0.0	0.0	0.8	2.6	2.8	4.6	4.5	6.0	3.8	4.3	2.5	4.9	6.8	6.8	6.9	6.9	5.0	4.8	4.4	4.9

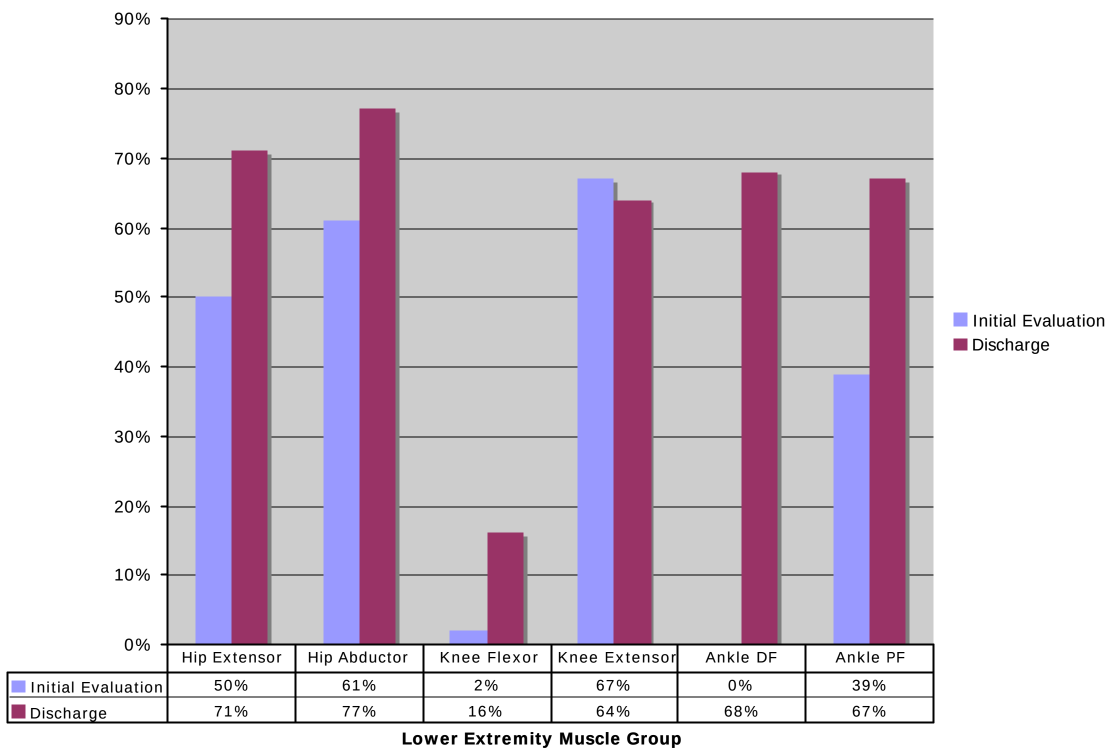
Re-evaluation Consultation

Figure 10. Changes over time in right and left dorsiflexion strength at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



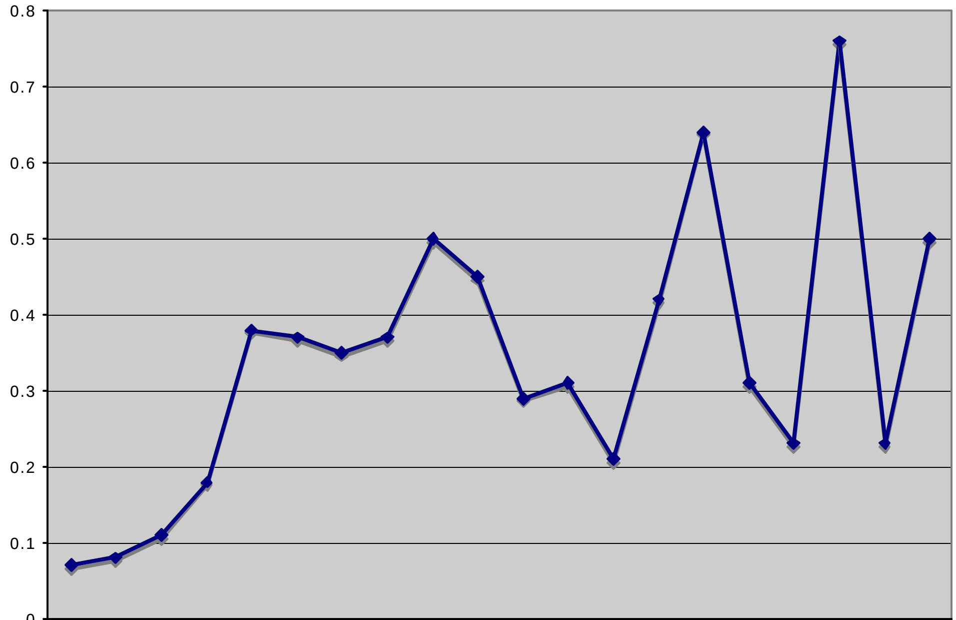
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Right	21.5	18.5	21.1	24.9	23.9	22.2	17.7	22.9	21.3	19.3	24.8	20.3	32.0	25.3	22.4	26.2	29.3	31.2	31.0	21.4	19.3
Left	8.3	6.5	14.9	16.8	13.9	17.0	13.6	20.9	12.3	15.1	24.2	20.8	18.7	17.5	17.6	16.1	19.7	17.2	11.1	15.1	13.0

Figure 11. Changes over time in right and left plantarflexion strength at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	Hip Extensor	Hip Abductor	Knee Flexor	Knee Extensor	Ankle DF	Ankle PF
Initial Evaluation	50%	61%	2%	67%	0%	39%
Discharge	71%	77%	16%	64%	68%	67%

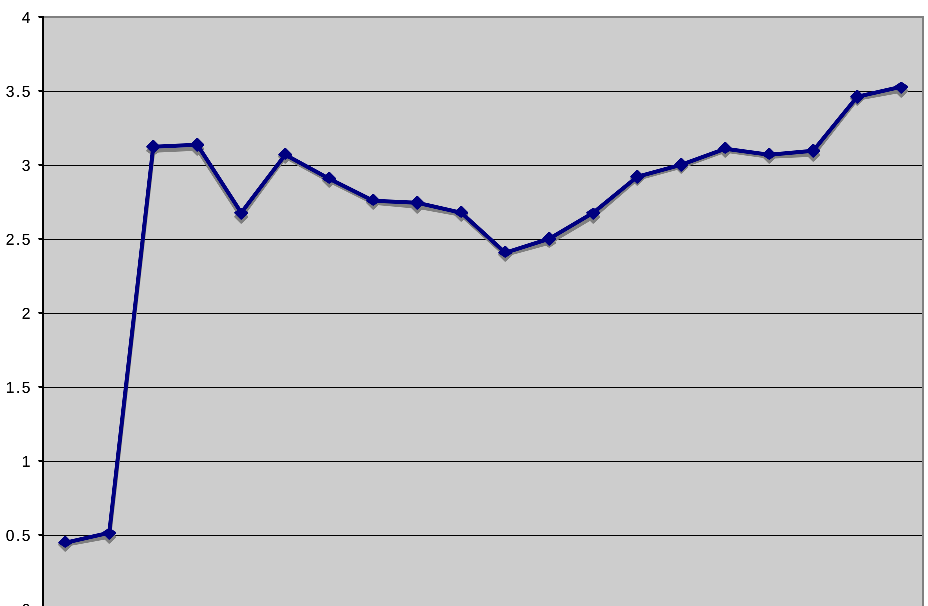
Figure 12. Percent strength ratio of right lower extremity strength over left lower extremity strength from initial evaluation to discharge of a 17-year-old male subject with a TBI.



	1	3	4	5	6	7	8	9	11	12	13	14	15	16	17	18	19	20	21	22
Series1	0.07	0.08	0.11	0.18	0.38	0.37	0.35	0.37	0.5	0.45	0.29	0.31	0.21	0.42	0.64	0.31	0.23	0.76	0.23	0.5

Re evaluation Consultatior

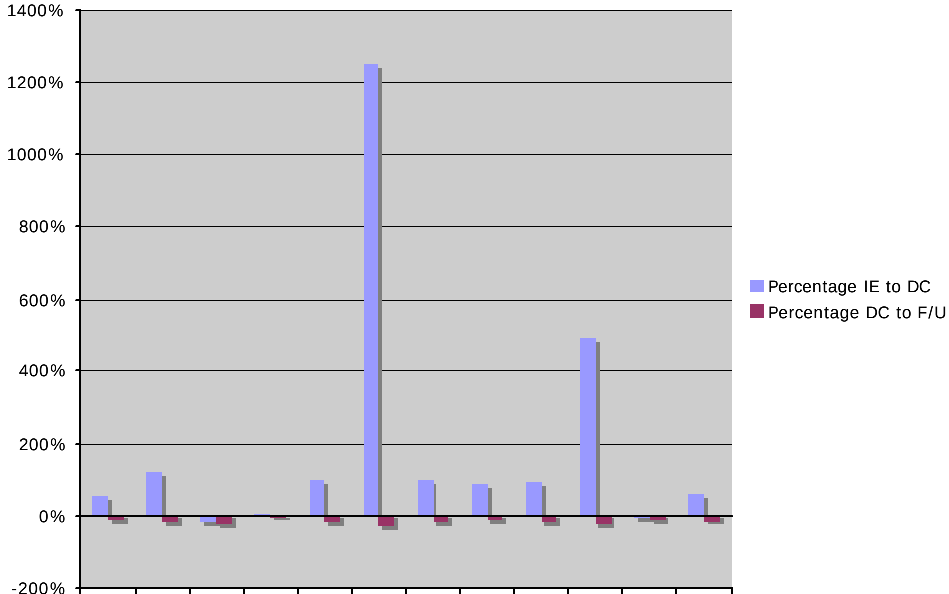
Figure 13. Changes over time for running distance at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	1	3	4	5	6	7	8	9	11	12	13	14	15	16	17	18	19	20	21	22
Series1	0.45	0.51	3.12	3.13	2.67	3.07	2.91	2.76	2.74	2.68	2.41	2.5	2.67	2.92	3	3.11	3.07	3.09	3.46	3.52

Re evaluation Consultatio

Figure 14. Changes over time for running speed at two-week re-evaluation intervals between admission and discharge of a 17-year-old male subject with a TBI.



	ave R hip ext	ave L hip ext	ave R hip abd	ave L hip abd	ave R knee flex	ave L knee flex	ave R knee ext	ave L knee ext	ave R df	ave L df	R pf	L pf
Percentage IE to DC	54%	120%	-20%	1%	97%	1250	97%	86%	89%	490%	-10%	57%
Percentage DC to F/U	-13%	-19%	-24%	-5%	-17%	-31%	-19%	-14%	-17%	-27%	-12%	-17%

Figure 15. Percent strength change between Initial Evaluation to Discharge Date and Discharge Date to Six month follow up of a patient with a TBI.