Splinting the Hand to Enhance Motor Control and Brain Plasticity

Donald Greg Pitts and Shirley Peganoff O'Brien

Theoretical constructs on the values of splinting the hand are reviewed. Therapists treating poststroke patients face a fast changing technology environment. This new technology allows scientists and physicians the opportunity to evaluate brain function. Scientists can increase understanding of the effects of stroke on function based upon location and severity. Physicians can evaluate the effects of medication and their interaction with the brain. Technology is unmasking the brain's vast ability to adapt and restore function due to its plasticity. Therapists must be diligent to gain knowledge of this everchanging science. Current research challenges the efficacy of splinting patients who are post stroke. If muscle and joint systems are allowed to become stiff and nonfunctional, what becomes of the sensory input to the brain? Now more than ever, therapists have an opportunity to apply motor reeducation with functionally based tasks and demonstrate the value of rehabilitation. This will only be realized if the peripheral muscle and joint systems are kept at a functional length. Custom splints applied after careful evaluation and as a adjunct prior to treatment will maximize functional outcomes. **Key words:** *brain plasticity, poststroke, splinting, rehabilitation*

The purpose of this article is to present a conceptual foundation for the use of splints to enhance functional outcomes and affect plasticity of the brain after injuries as a result of stroke. Therapists must hone evaluation skills, clinical reasoning, and problem-solving skills in order to properly apply a splint to a patient with abnormal tone. Therapists also must evaluate the different types of connective tissue and understand the synergistic effects of stress and stress deprivation.[1] Only then will the therapist's treatment options set a favorable stage for occupational performance of functional activities to produce a positive change for brain plasticity.

Background

The brain homunculus contains a total body map for both a sensory and motor tract, and each body part is represented based upon percentage of use with functional tasks.[2] The space dedicated to the hand makes up between 25% to 30% of the entire sensory and motor homunculus. Until recently, it was assumed that the cortical maps of sensory perceptions were hard-wired in the pathways during early childhood development. However, new research suggests that the cortical map can change with functional use and has a high degree of plasticity.[2]

Hand and upper extremity disuse can create many pitfalls resulting from a decrease of sensory motor input and stress deprivation of connective tissue.[1] Patients may develop fear and depression with a loss of social roles and a decrease in activities of daily living (ADL) skills. Such patients often complain of an increase in pain reflex with a change in muscle-tendon length and fibrotic change in joint capsules and ligamentous structures. Muscle fiber type can change with disuse from slow twitch to fast twitch. Atrophy of muscle cross-sectional area can occur and limit force potential with ADL activities.[3]

Donald Greg Pitts MS, OTR/L CHT, *is Member and Clinical Director, Kentucky Hand and Physical Therapy, Lexington, Kentucky.*

Shirley Peganoff O'Brien, PhD, OTR/L, FAOTA, *is Associate Professor of Occupational Therapy, Eastern Kentucky University, Lexington, Kentucky.*

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Functional MRI for cortical mapping has been shown to be successful in young children with the congenital deformity syndactyly where the fingers are webbed, disallowing independent functional use with ADL tasks. Once surgical separation of fingers occurred, the cortical distinctiveness of the homunculus was altered and the brain reflected new fingers.

Even in nonaffected adults, the use or disuse of the hands can alter the afferent sensory pathways and dramatically change the interneuron connections.[2] In a case study of an individual with bilateral hand transplant, the brain gradually reorganized until the brain homunculus responsible for controlling the hands and arms resembled that of a healthy person. Major changes were initially seen after the first 6 months, when the patient began to flex his fingers with functional tasks.

In 2001, Dr. Betty Abreu (personal communication) suggested that therapists should focus on functional activities that are related to the specific hemispheres of the brain. The left hemisphere has sensory motor control over the right side of the body and also controls language, reading, reasoning, writing, and numerical computation skills. The right hemisphere controls the left side of the body including musical awareness, imagination, art awareness, and three-dimensional formation. Cortical plasticity training with skilled motor control reaching tasks can produce an expansion of wrist and digital representations within the motor cortex. An understanding of the functional representation is important for insight into treatment options post cerebrovascular event.

Motor control engaging the entire upper extremity in goal-directed purposeful tasks has been demonstrated to stimulate the sensory and motor cortex and restore coordination. Tasks must be appropriately graded with resistance and duration to disallow fatigue and depression in the patient. Current studies where rehabilitation has been focused on task-related activities show more promising results. Recent evidence indicates that mimicking a task, such as reaching for a cup without the cup being present, results in different patterns of movement compared to the same task performed with the object. Patients with upper motor neuron lesions often have motor control limitations as a result of fatigue from poor general physical condition and mental limitations from cognition impairment. Central fatigue was first discussed by NASA.

The NASA program discovered that the astronauts became incredibly fatigued when conducting fine-motor dexterity activities during repair of the space station. Therefore, NASA changed its training programs to reflect functional activities in a similar physical environment (i.e., water) while astronauts were wearing a spacesuit. This detailed work simulation training enhanced mental concentration and physical performance essential to NASA's missions. This detailed environmental and physical training program demonstrates that pure work simulation maximizes motor control from a cortical and physical level (Dr. John Lawrence, personal communication).

In 1985, Dr. Paul Brand described hand motor control as a product of brain, spinal cord reflexes, muscles, and peripheral end organs working together to form a sensory motor feedback loop to create meaningful function.[4] Brand believed that this continuous sensory-motor biofeedback loop could be altered if stress deprivation occurs in connective tissue. If joint protection with safe position splints and muscle length maintenance or restoration with static progressive splints is ignored, peripheral tightness will diminish potential for sensory motor input and controlled motor output. Motor cortex representation can diminish with immobilization beyond 9 days.

New studies with functional magnetic resonance imaging (fMRI) have been conducted to determine brain plasticity following a stroke.[5] Although most of these studies indicate general brain patterns, they are inconclusive regarding exact predictability of function status after the stroke. This makes prediction of functional outcomes very difficult and long-term management vital. Therapists treating poststroke patients must have the foresight to predict the pitfalls and protect connective tissue from stress deprivation that leads to tissue remodeling and joint contractures.

Lannin conducted a randomized control study on the effects of splinting to control wrist joint contracture.[6] The study included 63 adults who had experienced a stroke within the preceding

8 weeks. All participants were randomly placed either into a control group with therapy only or into one of two intervention splint groups with therapy. Participants in one splint group wore their splints in a neutral wrist posture, while participants in the second group wore them in an extended wrist posture. These night splints were worn from 9 to 12 hours overnight for a 4-week period. The assessor was blinded to the research question of change in extensibility of the wrist and long finger flexor muscles. This study assumes that dense and loose connective tissue will have an adaptive shortening in 4 weeks. However the results of splinting for 4 weeks had no significant change in extensibility of tested tissue. The rationale that immobilization splinting would create a positive change in the length of tissue with no contracture present over a short duration is not a common method applied in hand therapy. If patients have long-term problems with slow progression in rehabilitation and exposure to dangerous flexion postures remain, the probability of developing a contracture increases. The control group and splint groups all received active rehabilitation in a early 8-week poststroke period.

Tissue not stressed with active rehabilitation and protective immobilization (safe position) splints and corrective static progressive (mobilization) splints regularly over a long term stand a greater chance of permanent soft tissue remodeling and contracture. Pandyan demonstrated that upper limb positioning can reduce the incidence and severity of contracture in acute stroke patients.[7] The study found that patients most prone to contracture formation showed no signs of early functional recovery in 2 to 4 weeks after the stroke. Contracture formation consistent with adaptive shortening/remodeling was seen after the 4-week period. In 2005, Ada researched the effects of a 30-minute program of positioning the shoulder in maximum external rotation.[8] The report found that daily positioning significantly reduced the initial development of contractures in the shoulder. This program should be initiated early in a rehabilitation process for stroke patients with a low activity level in the upper extremity to realize the best functional outcome. These studies demonstrate that research outcomes vary and further study is needed on long-term splinting programs to evaluate and employ best practices.

Figure 1. The effects of chronic spasticity and the impact of adaptive shortening and joint contractures.

Stiffness

Poststroke patients often present with limited functional range of motion due to a common flexor synergy pattern or flaccid (no muscle tone) upper extremity. Peripheral tightness starts primarily with immobilization of joints and muscles in the presence of low or high tone. Stiffness, a result of stress deprivation, creates functional limitations and can lead to permanent muscle adaptive shortening and joint contracture (**Figure 1**).

Immobilization and untreated edema in the hand will mature to a fibrotic state.[1] This can create joint capsule deformation/remodeling and possible joint contracture. Muscle with no active or passive stress (stress deprivation) will develop adaptive shortening/remodeling of the intrinsic and extrinsic musculature.[4] This stress deprivation can create the classic stiff hand pattern with loss of joint function. The stiff hand posture presents with the metacarpal phalangeal (MCP) joints in extension and the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints in flexion.[4,9] If this "open pack" joint posture is allowed, the hand will become stiff due to stress deprivation of the ligaments and capsule of the joint system.

Scapular dysfunction and shoulder stiffness are additional problems resulting from immobilization and lack of motor control.[1] Therapists should make restoration of a normal scapular rhythm and scapular stabilization primary rehabilitation goals. Manual therapy and positioning of the entire upper extremity (shoulder, elbow, wrist, and hand) are vital to restore muscle balance and proper sensory motor input to the brain.[10] If aggressive manual therapy is applied to any stiff joint of the upper extremity, a dysfunctional pain reflex will develop. Pain reflexes can create many obstacles to a safe and effective rehabilitation plan. These obstacles include soft tissue flare, fear, depression, and anxiety with loss of social roles. This is common when inappropriate stretching techniques or poorly fitted prefabricated splints are applied to a patient with high tone. Patients can develop heavy co-contraction and muscle guarding, which results in peripheral tightness and increased spasticity.

Reflexes

Often well-intentioned therapists and caregivers apply a stretching program to patients with upper motor neuron lesions. If this program stimulates the pain reflex, it could be counterproductive to rehabilitative goals of restoring functional change in the length of the affected muscles. Therefore therapists must understand the basic science of reflexes. The pain reflex initiates co-contraction of the agonistic and antagonistic muscles simultaneously to stop the painful stimulation of the stretch.[11] Cortical involvement of this process increases the state of muscular tension and purposely creates a lack of functional movement. The pain reflex speed is between 25 to 50 ms and fires fast twitch muscle fibers before slow twitch firing. This pain reflex has great potential to inhibit function. It is important that therapists evaluating occupational performance and functional tasks view muscles as sensory end organs. A stretched muscle distorts the muscle spindle causing a sensory impulse to travel the central nervous system (CNS) in the form of a stretch reflex.[11] Muscle spindle apparatuses are located within the muscle belly. The sensory input travels up the afferent nerve fibers into the spinal cord and synapse with the alpha motor neurons resulting in a gain in contraction potential of the particular muscle that has been stretched. This is known as an autogenic or muscle stretch reflex. The muscle spindle apparatus sends crucial information to the CNS pertaining to the velocity of motion and the amount of stretch that occurs with all tasks. This creates a motor memory critical for dexterity, force regulation, and power production. Muscle spindles are under constant tension, even while the muscle is shortening, with constant monitoring by the gamma reflex. The resulting reflex allows a continuous sensory feedback loop between the CNS and peripheral nervous system with the muscle physically engaged in all forms of functional activity.

The gamma reflex takes up slack in the muscle spindle apparatus to allow stimulation and awareness through all phases of concentric and eccentric motion. This allows for coordinated movement and appropriate muscle tone while functional activities are being conducted with subconscious and/or conscious intent. Inhibition of the gamma motor neurons for the antagonist muscles at the spinal cord level diminishes sensitivity to stretch so that smooth active range of motion can occur with ADL tasks. For example, when you transition a cup of coffee from the table to your mouth, the gamma reflex is inhibited to allow full lengthening of the triceps muscle. This allows coordinated functional motor control with the biceps and hand to deliver the coffee to your mouth without spillage. Over time, the brain remembers this ADL task and estimates the weight of the cup and applies proper force regulation to the task.

In patients with spasticity, the stretch reflexes are altered with an increase in excitability to stretch and diminished inhibition to the antagonistic muscles. Clinically, the defining characteristic of spasticity is excessive resistance of a muscle to passive stretch. Therapists identify spasticity through an increase in resistance to movement with an increase of velocity applied to stretch.[11] Muscle tone can be identified by sustained stretch tension that resists an increase of resistance. High muscle tone disallows or limits passive range of motion of a joint. Normal or low muscle tone allows full passive motion with restriction at end range as a result of joint and ligament restriction.

All of these impairments can have a major impact on motor control and functional outcomes. Therapists must have the analytical skills to evaluate the level of mental and physical dysfunction and treat the impairments of individuals who have sustained a stroke. Splints that are custom fabricated can be used to apply appropriate safe stress to stiff joints and tight muscles that will promote prevention of contracture and restoration of function. This can maximize outcomes and restore functional length of stress-deprived connective tissue, which will enhance a comprehensive rehabilitation plan.

Dense and Loose Connective Tissue

There are two types of connective tissue: collagen and elastin.[1] Collagen is very dense and strong and has similar properties to steel. Elastin has very elastic properties and has reversible strain up to 200%. Dense connective tissue is primarily made up of collagen fibers and is present in ligaments, tendons, joint capsules, and bones. Collagen has 10% elongation before permanent deformation. Loose connective tissue can be found in muscles, nerve sheaths, and skin. Connective tissues have the potential to demonstrate an adverse response (joint stiffness and muscle adaptive shortening) if allowed to remain in postures that allow stress deprivation.

Studies on rodent joints after immobilization demonstrate that stress deprivation leads to a significant decrease in glycosaminoglycans (gag), chondroitin, and hyaluronic acid.[12] Immobilization from a loss of functional use can result in the following: (a) loss of ground substance and lubrication, (b) diminished nutrition and blood supply to the region that is impaired, (c) degeneration of cartilage and cartilage substance, (d) disuse atrophy, (e) muscle imbalances of intrinsic and extrinsic muscles, (f) loss of sarcomeres with permanent muscle shortening, and (g) binding of facial elements with change in functional length.

Stress–Strain Curve

A stress–strain curve is important to understanding stress deprivation.[1,4] Strain is the change in length relative to the initial length when stress is applied to soft tissue. Stress is the amount of applied force to soft tissue per unit area. Stiffness is the slope of force length or stress–strain graft. The amount of soft tissue stretch (strain) in response to applied force (stress) depends upon its physical properties.

Dr. Paul Brand demonstrated in his research that, with increased stress, soft tissue will actually lengthen and grow to accommodate the stress.[4] His clinical observations noted that the stress application must occur below a pain reflex. Brand believed that the level of physical stress must be enough to create change but not in excess to avoid an inflammatory response. Therapists apply stress with dynamic and static progressive mobilization splints to reset the elastic normal limit of loose and dense connective tissue.

Therapists must understand the basic treatment principles of dysfunctional dense and loose connective tissues for the proper application of splints to restore function.[1,4,10] These basic treatment principles regarding stress application and their effects on soft tissue include mechanical and biological creep.[13]

The biological creep technique involves carefully placing dense connective contracted tissue under constant safe stress. The tissue then accommodates to the force with cellular growth and the physical stress is diminished and a new length is established. This technique creates safe gradual change in the resting length of the soft tissues and reduces the chance for undesirable soft tissue tearing that initiates the inflammatory response. This is an excellent clinical approach in treating dysfunctional dense connective tissue. The clinical application of this technique is commonly seen with static progressive splints and serial casting, that is, inelastic mobilization splinting. The mechanical creep technique may involve the application of a steady dynamic or manual manipulation force.[1,4,13]

The force is dynamic and creates displacement of soft tissue until the resistance of the tissue equals the applied force. The clinical application of this technique is with dysfunctional loose connective tissue. Caution must be taken to avoid an adverse flare reaction to sore joints or tight muscles. The clinical application of this technique includes all forms of dynamic splints (mobilization splints) to correct, protect, and promote functional restoration. The biological and mechanical creep techniques rely on the force application principle of a total end range time (TERT). TERT promotes safety and will affect tissue change if the stress time application is dosed to an effective level. This requires a minimum of a 2 hours (mechanical creep) up to 8 hours (biological creep). The build-up of dose time may be slow and requires constant monitoring in the initial phase of the splint fit to avoid irreparable damage to soft tissue. Loose connective tissue will have a rapid positive change early in the splinting program. Dense connective tissue will have a slower response, with change at a rate of 3%–5% per week. The TERT principle is most critical to the success of a comprehensive splinting rehabilitation program.

Evaluations

Evaluations are the most critical part of a rehabilitation program and must be completed in detail before application of splints. The evaluation should be comprehensive to ensure a holistic approach in establishing detailed rehabilitation goals. Initial gathering of demographic data is critical to determine the severity index of the stroke. A complete medical history and an assessment of both the patient's and caregiver's expectations are essential in establishing strong team rehabilitation goals. The evaluations should focus on how the stroke has impacted the patient's social roles and ADL performance. Understanding a patient's motivation and typical pattern of occupational performance provides therapists with key information for collaborative treatment planning.[3] Research has demonstrated that patients' outcomes are more readily attained and satisfaction is greater when they are involved in setting meaningful goals.[14] The Canadian Occupational Performance Measure (COPM) is an excellent tool to interweave into the patient interview to set goals. Functional motor control deficits and biomechanical limitations are best evaluated through patient engagement using tasks and manual assessments.

Poststroke patients have many problems that can decrease their function with ADL tasks. The most common deficits include but are not limited to cognition, depression, visual acuity, sensory input, soft tissue shortening, and low tone (flaccid) or high tone (spastic). Patients can present with difficulty generating and sustaining control necessary for effective motor performance with ADL tasks. This loss of motor performance can be a result of (a) limited motor unit activation, (b) changes in the order of motor unit recruitment, (c) poor muscle force regulation in consequence of limited inhibition with ADL tasks, and (d) loss of selective control of voluntary movement. These are a few common but major problems that should be considered during evaluation.[11]

Connective tissue biomechanical evaluation and function

Therapists must have a clear biomechanical understanding of the hand and how all its systems work in synergy to create function.[1,10,15] Joint function in the open and closed pack postures must be evaluated to control for contracture. The hand MCP joints, wrist, and elbow should be closely monitored and splinted prophylactically. The therapist must understand normal joint function. Joints must have roll, glide, and spin to realize normal kinematic movements. Evaluation of these joint functions is critical in determining stability of a joint and safe application of mobilization splints.

Muscle adaptive shortening

Muscles subjected to a prolonged position without stress will develop adaptive shortening/remodeling of the tissue.[1] If muscles are rarely exposed to active and passive stress, the tissue will undergo cross-sectional bridge changes and will lose sarcomeres. They will become short and stiff and resistant to stretch as a result of mechanical change in length.[16,17] This adaptive shortening will change a patient's ability to provide appropriate grasp reflex with wrist extension, which enhances digital flexor motor recruitment and force regulation. Such patients can become easily fatigued and develop poor motor control due to a change in muscle length and muscle imbalance.

Extrinsic muscle tightness can often be evaluated through a simple measurement of dorsal and volar compartment lengths. The patient is asked to place the arm and elbow in full extension, make a fist, and bring the wrist into volar flexion. This will determine functional length of the dorsal compartment or extrinsic extensor mechanism. If the stroke patient cannot actively do this and the therapist can passively do this and measure joint range of motion, this will determine the functional length of the extensor mechanism and establish treatment goals. Normally, in patients with high tone and high spasticity, there will be inappropriate lengthening and weakness.

The volar compartment length is measured with elbow extended and wrist in dorsiflexion and fingers extended. Again, the patient can be tested in a passive range of motion, if poor motor control or limited cognition is present. Normally, this muscle structure is extremely tight and will demonstrate extrinsic flexor tightness and limited functional length.

Evaluation and treatment of the intrinsic lumbrical musculature is critical to future fine motor dexterity skills. The lumbrical muscles act as the edema pumps for the hand. Their primary function is flexion at the MCP joints and extension at the PIP and DIP joints. The lumbrical muscles are critical to create appropriate muscle balance. If balance is lost, full force potential and force regulation of the extrinsic flexorscan be altered. Therapists should take careful note to evaluate lumbrical stiffness. This is accomplished by extension of the MCP joint and active flexion of the PIP and DIP joints. If this is limited more than when the MCP is flexed, then the patient will present with lumbrical tightness. Lumbrical muscles are directly connected to the tendons of flexor digitorum profundus muscle, the large workhorse of the hand and provider of power grip. Therefore, if the lumbrical muscle is tight, the patient will have a difficulty in initiating maximum force potential and force regulation with ADL activities.

Edema

Edema evaluation can be done through circumferential measurements or through use of a volumeter, if the patient's tone and posture will allow.[9] The volumeter is a consistent and repeatable evaluation for determining the severity of edema when used according to the manufacturer's instruction. It also assesses whether treatment interventions diminish the edema. Therapists will often use inconsistent circumferential measurements. This assessment tool is inconsistent due to the stretch of the tape measure, inability to regulate force application with the tape measure, and inconsistent placement of the tape measure. Brand, in his research, observed that edema left untreated will result in scar formation, adhesions, joint deformity, and muscle imbalances.

Sensibility evaluation

Sensory evaluations are critical to determine whether the patient has integrity of light-touch deep-pressure nerve function in the extremity.[15] These evaluations can determine whether the patient will be safe around hot and sharp objects in a home or work environment. The patient's cognition and understanding of the testing can be a roadblock in determining whether sensation is intact.

Prioritize the treatment of stiffness

It is important that therapists identify those problems that create the largest drag on functional movement and sensory motor input to the brain. This requires continuous evaluation of the current situation with rehabilitation goals set daily, not weekly. Therapists should prioritize treatment of stiffness, looking for joint dysfunction and muscle imbalances. If joint and muscle lengths can be restored and maintained, the patient will decrease the number of obstacles that limit return to function.

Splinting

Splints to restore function have been widely used by therapists for many years.[5,18] Splints are the primary adjunctive tool used to prevent stress deprivation in ligaments, joints, and muscle tissue. The application of splints to prevent or correct deformity requires the therapists to understand the physical mechanical properties of both loose and dense connective tissue. Stress application that is controlled and graded to all types of connective tissue can restore functional length and avoid an undesirable inflammatory response. One of the most common clinical problems is adaptive shortening/remodeling of the muscles. This is a change in fiber length that, along with a decrease in cross-sectional area, will greatly diminish the power potential of muscle. Soft tissue adaptive shortening/remodeling has been observed to begin in as little as 4 weeks in a nonfunctional joint.[7]

Advantages of splinting

Splinting can stimulate brain function by maximizing the functional length of both intrinsic and extrinsic muscles and by maintaining appropriate joint structure function.[5,8] Splinting prepares the hand and upper extremity for functional retraining. It also preserves joint integrity. Splints can change muscle length and the muscle tension relationship between the intrinsic muscles and the extrinsic flexor and extensor muscles. This is critical for an appropriate and functional grasp reflex. Custom splints can increase the potential for sensory-motor input, with the result of maximizing functional length and the hand's ability to do gross motor and fine motor dexterity tasks.

Splinting prevents peripheral tightness of the extrinsic flexors. It can prevent adaptive lengthening of the extrinsic extensors and prevent joint deformity of the wrist, MCP, PIP, and DIP joints. Splinting assists in restoring muscle balance and in diminishing the drag of muscle and joint so the injured brain can maximize functional sensory-motor input. Splinting helps improve ADL capacity and restore social roles and diminish the drastic effects of hand dysfunction.[13]

To make a good splint, therapists must have a good understanding of thermoplastic material properties that include drapability, elasticity, durability, rigidity, flexibility, bonding, and memory.

The application of splints should be based upon clinical evaluation and long-term treatment goals. In the acute stroke patient, the immediate goals should be to diminish adaptive muscle shortening, reduce and prevent edema, and protect the joint system. This is normally realized through custom-made, forearm-based safe position splints. These splints are applied using materials that have good memory and durability. Orthoplast is a good example of a material that will allow the therapist a long work time and forgive heavy handling to provide positioning to patients with high tone. This material allows the therapist to apply Ace bandages while splinting a patient with high tone and then set the hand in the appropriate length–tension relationship based upon the patient's current situation with regard to tone, spasticity, and joint contracture.

Splinting low vs. high tone

Low tone. In applying splints to patients with low tone, therapists should place the hand in the classic safe hand posture with the MCP joints in 70° to 90° of flexion and the PIP and DIP joints in full extension.[6,9,18] The wrist is placed in 30° to 40° of extension. This splinting posture will safeguard the hand and wrist against abnormal tissue shortening as a result of stress deprivation/remodeling. The length of the volar splint should be at least two thirds up the forearm. This provides a large lever arm ideal to control tone when applying stress through the wrist and digits. The width around the forearm should be a minimum of two thirds. This disallows forearm rotation and enables control of wrist posture. Straps are secured with rivets to meet Medicare expectations, to improve positioning of the hand, and to ease application for cognitive limitations. The splint normally requires four straps with the most distal first across the PIP joints, the second across the metacarpals, the third across the carpus, and the fourth at the proximal end of the splint. Wear time should be a minimum of all night. The splint may also be worn during the day if edema reduction is a primary goal.

High tone. Before application of the resting hand splints for patients presenting with high tone, the therapist must do a thorough evaluation of the joint system and the muscle length of the extrinsic extensors and extrinsic flexors. The functional length approach is helpful to evaluate the length of the extrinsic flexors in layers. The length of the flexor carpi radialis and flexor carpi ulnaris are completed first. This is accomplished by evaluating the wrist's maximum ability to move through a passive range of motion into dorsiflexion with wrist only, leaving fingers unstressed. This will test the top, or superficial, layer of flexors. Next, the therapist, while still maintaining stress on the superficial layer, can apply stress to the second layer, which is the flexor digitorum superficialis. This will determine the length–tension relationship between the superficial wrist flexors and the second layer superficial digit flexors. Finally, the therapist will apply stress to the FDP, deep digital flexors. This is a critical evaluation to determine the length– tension relationship between the three layers of muscles, superficial wrist versus the superficial digital versus the deep digital flexors. Once this relationship is determined, then the appropriate safe position splint can be designed and fitted.

If the therapist attempts to apply too much stress, particularly to the extrinsic superficial digital flexors (FDS) and the deep digital flexors (FDP), the patient will realize a poor result with excessive stress being applied to the three layers. Once the initial application of the splint occurs, the therapist then can gradually change the force application on the extrinsic thumb muscles and the extrinsic finger flexors in a controlled manner. This approach will require a progressive application of a safe position splint as described earlier for the low tone patient. A routine change in splint fit will be necessary to reach desired therapeutic goals. These splints are considered to be protective and corrective in application and design based upon physiological joint function and the stress sequence of the muscle length–tension relationship of the extrinsic hand and wrist muscles. Once a good safe position has been established with the patient, the splint application will be critical to avoid a dependent position and muscle adaptive shortening. The splint wear schedule should be all night and half-time day. If new soft tissue lengths can be established through safe position splint, ADL performance with gross motor tasks can be initiated

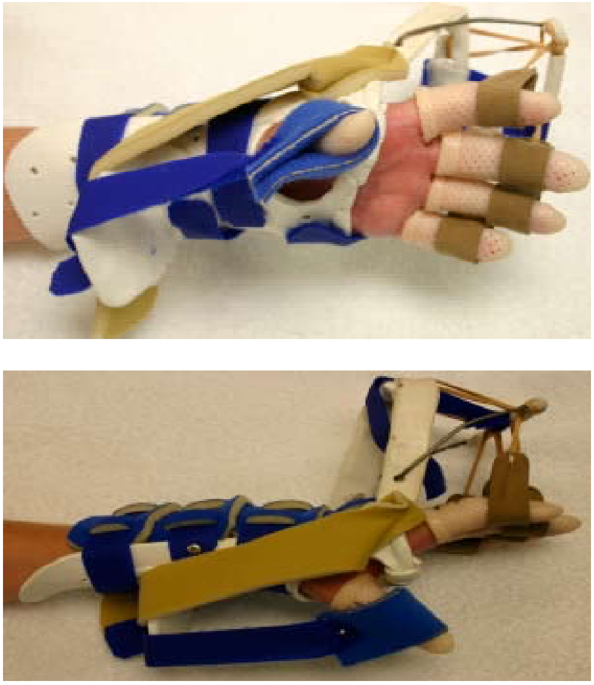

Figure 2. Forearm-based dynamic extensor outrigger with a crane attachment. The splint also has a volar post to apply graded stress to the web space and extrinsic thumb flexors. The crane and digital tubes allow the therapists to apply graded stress to the extrinsic flexor digital muscles tight from spasticity and adaptive shortening. Split goals are to restore or maintain brain potential to relearn functional motor output, disallow stress deprivation to muscle and joint system, provide graded constant input to reset muscle spindle apparatus, change/restore the length tension relationship of muscle groups, and allow clinician to reestablish balance in the hand.

Dynamic static progressive splints and mobilization splints can be used to apply gradual stress to the extrinsic digital flexors to enhance excursion potential and diminish muscle tone.[12,17,19] The splint is of simple design with a combination of a wrist gauntlet and a high profile extensor outrigger (**Figure 2**). The digital tubes are constructed with a circumferential fit. The length of the digital splints extends from the tip of the fingers to the web space. The static progressive straps are applied to each digital tube and attached to the extension outrigger. This allows the therapist to adjust the tension of each digit based

Figure 3. Photos of Saebo Splints by permission of Mr. Hoffman.

upon the different individual tone. The splint wear time should be gradually increased to 2 hours on and 2 hours off during the day. When the splint is removed, the patient should engage in gross motor graded activities and weight-bearing tasks.[20,21]

The safe position splint should be worn at night. Optimally, splint wearing time is gradually increased to avoid the pain reflex. The Sabeo (**Saebo, Inc.,** Charlotte, NC) splint system has reached popularity in application in recent years. This system is of sound design and principle. Sabeo uses a flexible splint with progressive inserts (Sabeo Stretch) to increase force application based upon tone of the patient (**Figure 3**).

The Static progressive system (Sabeo Flex) uses a dorsal-based forearm splint with an adjustable outrigger. The digital splints cover the distal phalanx and middle phalanx to apply stress to the extrinsic flexors. This allows active flexion of the extrinsic digital flexors with functional retraining. These splints provide therapists a quality option to address the negative affects of high tone.

If overstretching occurs through inappropriate application of a static progressive mobilization splint, whether custom or off the shelf, a pain reflex will result and tone will increase not diminish. If the therapist allows inappropriate splint application to occur, then excessive stress will be realized to shortened high tone muscle tissue. This can result in soft tissue breakdown, finger joint volar plate injuries, and ruptures of the extrinsic finger flexors. Remember, soft tissue tearing, for whatever reason, results in increased inflammation and increased scar formation.

Treatment

A team approach must be utilized between a physician, patient, caregiver, and therapist. Treatment goals must be established to ensure good functional outcomes. This requires constant communication among all team members. Each team member must understand his/her role as well as the roles of the other team members. Physicians (team leaders) monitor the complete medical condition of the patient and administer medications to control spasticity and improve function. The physician also determines the type, dose, and methods of delivery for all drugs.[22] The therapists apply therapeutic modalities and manual skills to prepare the patient for motor control functional relearning tasks and occupation.[14]

Muscle stimulation to the extensors of the forearm and upper arm is used to produce reciprocal inhibition. This has a profound clinical positive effect on high tone patients, allowing them to engage in gross motor ADL tasks. Therapists' use and understanding of functional tasks continue to improve outcomes in patients who are post stroke. The power of occupational based motor tasks and their positive impact on brain plasticity are being researched daily by motor control scientists. Educational preparation of most therapists recognizes the need to engage stroke patients in basic ADL graded tasks to restore brain function, following the principles of motor control theory and occupational engagement. The use of functional occupation in the rehabilitation process has the potential to reinforce normal neuromapping for motor tasks and promotes functional outcomes.

Splinting the hand is one modality that can be used to prevent joint contracture and improve muscle length for patients with high tone and spasticity.[5,18,23] The bio-occupation foundation is critical to the comprehensive rehabilitation program, especially for the poststroke patient. Unfortunately, many professional curricula have all but stopped teaching the clinical reasoning skills and application techniques necessary to actively fit the stroke patient with custom resting and static progressive splints. The elimination of the psychomotor skill development has the potential to greatly jeopardize practice. If splinting content is not taught beyond a knowledge perspective, future therapists will not demonstrate necessary psychomotor skills to adequately respond to a client base, typical and growing in the rehabilitation needs.

Need for Research

There are important questions that can only be answered with additional research, for example: What are the long term consequences of brain plasticity for a stroke that develops contractures? Can joint contractures be reversed with surgery and medication alone? Will stroke patients have the ability to regain sensory input and motor control when new medications are developed if peripheral tissue is allowed to develop permanent muscle adaptive shortening?

The current research is limited with small sample sizes, incorporation of multiple interventions, and low duration of splinting applications and does not provide dependable information. The application of custom splints is vital and provides the rehabilitation team with a consistent tool to improve dysfunction and restore function. Many questions must be addressed in order to provide the best evidence for treating individuals who have sustained injury to the upper motor neuron system. Extensive research in this area is essential.

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