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HS Review

Comparing the Efficacy of Various Hand Splints in Post Stroke Recovery: A Brief Literature Review

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ABSTRACT

Stroke is the leading cause of long-term disability in the United States, according to the CDC, and causes reduced mobility in half of all survivors age 65 and over. Moreover, most stroke survivors suffer from impaired upper extremity function, and this debilitating impairment limits persons with stroke from performing basic activities of daily living; as a result, their quality of life is reduced. Splinting seeks to aid persons with stroke in gaining critical hand function through shaping the hand properly, reducing joint pain, preventing or treating muscle contracture and spasticity, and providing assistance. While there are many splints designed for persons with stroke currently commercially available, a majority of them can be classified as part of one of three categories: static splints, dynamic splints, and robotic splints. To examine how effective each kind of splint is at improving upper limb function after stroke, we reviewed the various designs of static and dynamic splints, their functionality, and mechanics, and summarized the study results from the literature. We also discussed both the current limitations of each design of splint, as well as designs and treatments that could be developed in the future.

Introduction

A stroke or cerebrovascular accident (CVA) occurs when the blood supply to a part of the brain is blocked (ischemic stroke) or when a blood vessel in the brain bursts (hemorrhagic stroke). As a result of the sudden loss of oxygen and important nutrients, strokes cause brain tissue to become damaged or die. Impairment often occurs due to this damage, resulting in physical conditions including weakness, paralysis on one or both sides of the body, coordination and balance issues, speech and communications difficulty, and limited mobility (The Internet Stroke Center). In order to treat upper limb immobility after stroke, splints are often utilized. A splint is a noncircumferential external device that is designed to apply, distribute, or remove forces to and from the body in order to maintain movement, reshape muscle tissue, or prevent muscular contraction (Jo, Chen, Zhang, Shang, & Carstanje, 2018). Splints are made with a variety of materials, from hard plastics to soft neoprene materials and fabric, depending on their structure and function of the splint in question. Static (immobile), dynamic (mobile), and robotic splints are the most commonly used splints on the hand (Jo, Chen, Zhang, Shang, & Carstanje, 2018).

While all splints are designed to improve range of movement and reduce muscle tone and contraction in the hand, static, dynamic splints, and robotic splints perform very differently when compared to each other. Static splints employ inelastic components in order to apply torque to a joint and statically position it. Typically, these splints must be worn throughout the day (around 8 hours) for the device to be effective (Andringa, van de Port, & Meijer, 2013). It is also necessary for some people to wear the splint through the night as well (Andringa, van de Port, & Meijer, 2013). Dynamic splints, on the other hand, integrate a tension spring into a brace in order to provide mild stress on joints in order to remodel the tissue. Robotic splints are the latest development in hand orthoses used for stroke recovery. Similar to dynamic splints, patients can perform rehabilitative exercises while wearing a robotic orthosis. However, unlike dynamic splints, robotic orthoses also make use of electronic components in order to assist the patient in moving their hand (Al-Quraishi, Elamvazuthi, Daud, Parasuraman, & Borboni, 2018).

Purpose of this Review

The purpose of this brief review is to summarize how effective each kind of splint is at improving upper limb mobility after stroke. We reviewed the various designs of static and dynamic splints, their functionality, and mechanics. We also discussed both the current limitations of each design of splint, as well as designs and treatments that could be developed in the future.

Static Splinting

Designs and Function

Static splints are orthoses that lack movable parts (Figure 1). They use inelastic components in order to apply torque to a joint in order to position it correctly and keep the arm and wrist in a "neutral" position to prevent muscle contracture. Static splinting has been a popular option in physical therapy for treating loss of upper limb motion and contracture after a stroke.

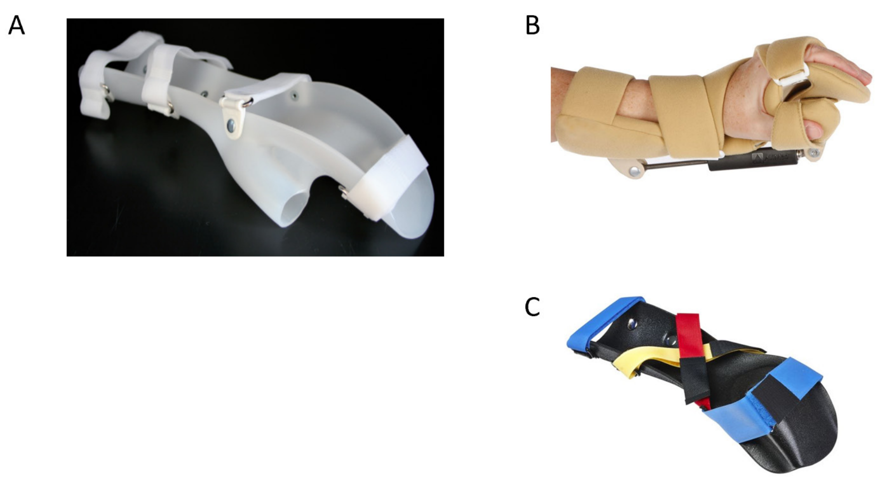

Figure 1: Examples of Static Splints. 1A- Plastic Static Splint orthosis (Andringa, Van de Port & Meijer, 2013). 1B- AliMed® Turnbuckle Functional Position Splint (Alimed Turnbuckle). 1C- AliLite™ Functional Position Splint (Alilite Functional).

Clinical Studies

Three articles investigated the effects of static splinting on post-stroke contractures and the findings on the efficiency of the static splints were inconclusive (Table 1). In one study by Smania et al., (2012) the experimental group receiving static splinting improved motor function and activity and decreased unwanted muscle tone when compared to the control group who underwent a conventional therapy program involving 20 minutes of passive mobilization, 30 minutes of exercise, and 10 minutes of standard Activities of Daily Living (ADLs) each day. Similarly, another study by Fujiwara, Kawakami, Honaga, Tocikura, & Abe (2017) reported that persons who received splint therapy performed better than the persons in the control groups on the Fugl-Meyer Assessment (FMA), motor activity log 14 (MAL), and Modified Ashworth Scale (MAS) scores. However, Andringa, van de Port, & Meijer (2013) reports that a significant number of participants stopped wearing the splint due to discomfort and a similar number reported that they were unable to tolerate the splint for the prescribed 8 hours per day due to pain and discomfort. This ultimately rendered the therapy less effective and putting them at a greater risk of developing a clenched fist.

Table 1. Results of studies on static splints.

Authors	Number of Participants	Design (RCT, single group, pilot or feasibility), add column for group assignment- experiment vs. control	Outcome measures	Results
Smania et al., 2012	66	Randomized Control Trial (RCT)	Wolf Motor Function Test (WMFT-FA and WMFT-T), Motor Activity log (MAL-AOU and MAL-QOM)	Participants from the experimental Constraint Induced Therapy (mCIMT) had a greater overall improvement in the WMFT-FA, MAL-AOU compared to the control group
Fujiwara, Kawakami, Honaga, Tochikura, & Abe, 2017	20	Single group study	Fugl-Meyer Assessment (FMA), motor activity log 14 (MAL), and Modified Ashworth Scale (MAS)	Participants showed significant improvement on FMA, MAL, and MAS scores at the end of the trial compared to the beginning.
Andringa, van de Port, & Meijer, 2013	11	Survey	Semi-structured phone interviews with participants	6 participants reported either poor or very poor comfort, 3 participants were unable to wear for the prescribed 8 hours

Dynamic Splinting

Design and Function

Dynamic splints are made of largely the same materials as a static splint; however, they contain components that allow for additional movement and assist in completing desired movements (Figure 2). This contrasts with static splints, which are completely immobile. Dynamic splints utilize an integrated tension spring to provide mild, long-duration stress upon restricted joints in order to remodel the tissue. These springs can be adjusted to add and take away tension and increase the range of motion. Dynamic splints also can contain other components, such as outriggers, elastic strings, and individual finger belts (Jo, Chen, Zhang, Shang, & Carstanje, 2018).

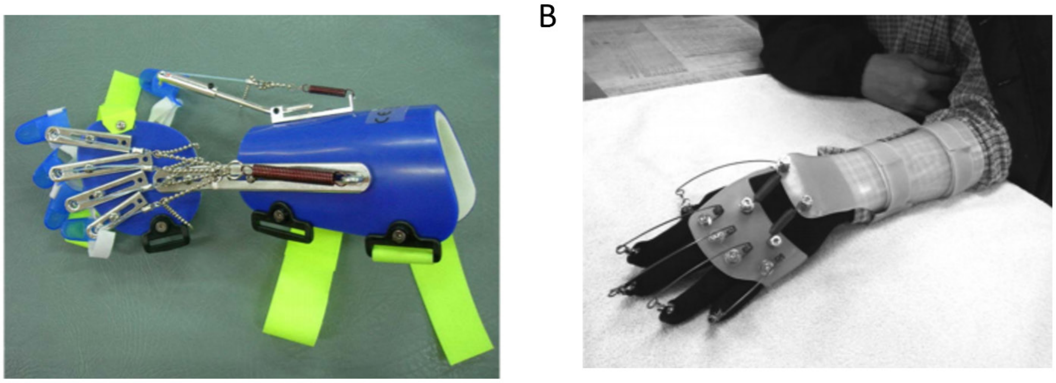

Figure 2: Examples of Dynamic Splints. 2A- SaeboFlex hand orthosis (Woo et al. 2012), 2B- Customized dynamic hand splint (Chang & Lai, 2015).

Clinical Studies

Four articles investigated the effects of dynamic splinting on hand contractures post stroke (Table 2). The findings on the dynamic splints generally pointed to them being effective. In one study (Woo et al., 2012), rehabilitation using a dynamic hand orthosis was proven to improve performance on the FMA and Box and Block test, as well as decrease jerkiness of the shoulder, elbow, and wrist joints. Similarly, Chang & Lai, 2015 showed that the use of a dynamic splint in a 3-month conventional rehabilitation program led to significant improvement in the maximal voluntary contraction of both the wrist extensor and flexor muscles as well as grip and finger strength. This suggested the usefulness of dynamic hand splints as a supplement to hospital-based rehabilitation. A study by Barry, Ross, & Woehrle, 2012 also showed that there were significant improvements in function with treatment with the dynamic splint, as seen when comparing the results of the Action Research Arm Test (ARAT) from before and after the study. However, the dynamic splint group did not perform better when compared to the group receiving manual assisted therapy. In one review, Jo, Chen, Zhang, Shang, & Carstanje (2018) suggested that, while dynamic splints have been shown to be most effective in improving hand mobility in stroke individuals, further studies are needed in order to develop standardized application techniques, understand whether dynamic splints reduce spasticity directly or indirectly, develop methods to measure the direct effect of splints, and more.

Table 2. Results of studies on dynamic splints.

Article	Number of Participants	Design (RCT, single group, pilot or feasibility)	Outcome measures	Results	Group Assignment
Woo et al., 2012	5	Feasibility study	FMA, Box and Block Test, Action Research Arm Test, and Kinematics using a three-dimensional motion analysis system	Improved performance on FMA, Box and Block test, as well as decreased jerkiness of shoulder, elbow and wrist joints.	
Chang & Lai, 2015	10	Single group study	electromyography, grip and finger strength appraisals, and Fugl-Meyer assessment	Significant improvement at end of trial in maximal voluntary contraction of wrist extensor, wrist flexor muscles, as well as grip and finger strength compared to before trial.	
Barry, Ross, & Woehrle, 2012	19	Pilot Study	Grip Strength test, action research arm test, box and blocks test, and stroke impact scale	Significant improvement in action research arm test compared to control, no significant difference compared to control on other tests.	Experimental group: therapy using SaeboFlex dynamic orthosis with therapist once a week for 6 weeks. Control group: Manual assistance therapy with therapist once a week for 6 weeks

Robotic Splint

Design and Function

Robotic splints are the latest development in hand orthoses used for stroke recovery (Figure 3). There are many varieties of robotic splints, but many of them work in a similar manner. The orthosis typically fits around the hand and forearm, using mechanical and electronic components in order to assist the patient in moving their hand. These splints often act in a similar manner to dynamic splints, providing tension to reshape the hand, while allowing functional movement. However, they have the added robotic components. Robot-assisted therapy has shown potential by allowing physical therapists to perform a lot less manual labor but get similar results. Additionally, some robotic splints can be controlled by the patient's own intention through the extraction of Electromyography (EMG) and Electroencephalography (EEG) signals by sensors on the device (Al-Quraishi, Elamvazuthi, Daud, Parasuraman, & Borboni, 2018).

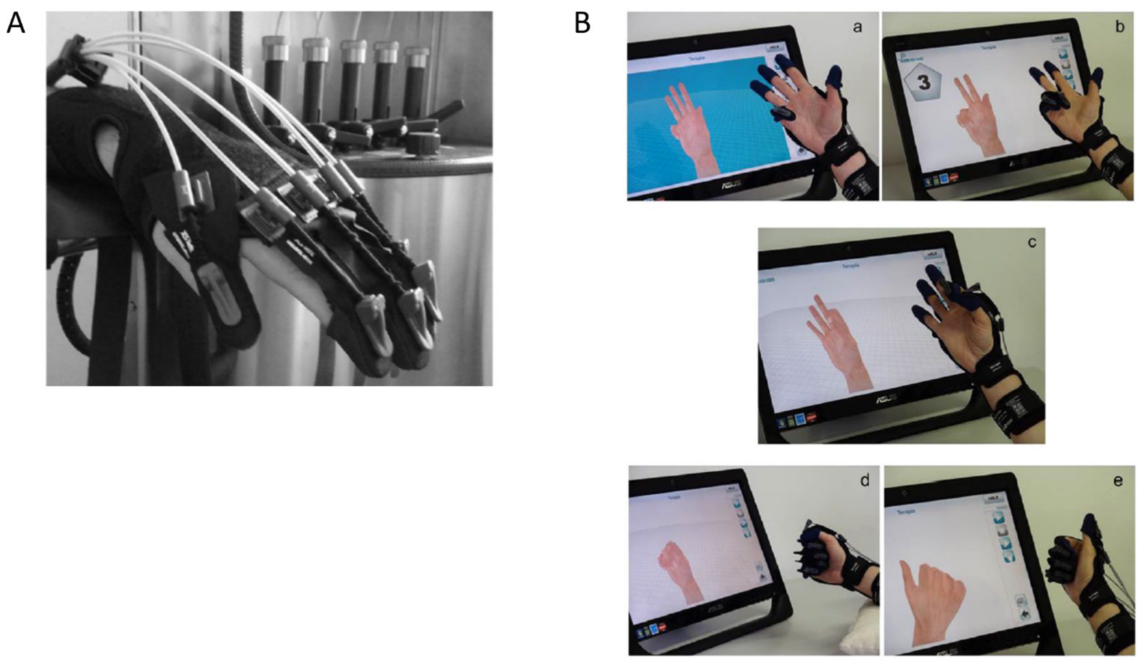

Figure 3: Examples of Robotic Splints. 3A- Gloreha Robotic Hand Rehabilitation Device (Villafañe et al., 2018) 3B-Hand exercises with Gloreha. Each finger was mobilized individually: a and b, number; c, pinch (thumb-index); d, fist; and e, synchronous, (II-III-IV-V finger are mobilized simultaneously, the thumb individually) in the presence of visual feedback. (Villafañe et al., 2018).

Clinical Studies

Five articles investigated the effects of robotic splinting and orthoses on post stroke hand joint contractures (Table 3). The findings on these splints pointed to them being effective. In one study by Yurkewich, Kozak, Hebert, Wang, & Mihailidis (2020**,** the participants showed statistically significant improvements in a water bottle grasp and manipulation task, index finger extension, range of motion, grip strength, and pinch force while using the glove. In another study, Yue, Zhang, & Wang, 2017, state that, while hand rehabilitation robotics have been greatly developed in recent years, there isn't sufficient research being done on them regarding their efficacy. Besides, many studies ignore the importance of evaluating the design of rehabilitation robots. One study using a wearable glove/orthosis, Gloreha, shows that after 3 weeks, participants who used the robotic device showed a greater reduction in pain compared to the control group, along with a significant increase in functional ability and motor strength (Villafañe et al., 2018). Results from a feasibility study (Vanoglio et al., 2017) also suggested that the glove is feasible in assisting with improving strength and recovering manual dexterity. Those using the glove experienced significant performance improvements in the motricity index, Nine Hole Peg Test (NHPT), and Grip Test, and Pinch Test compared to a control group that did not use the glove. One study (Orihuela-Espina et al., 2015) on the Tyromotion Amadeo glove showed that individuals using the orthosis experienced significant improvements in motor functioning and range of motion compared to a control group that underwent traditional occupational therapy.

Table 3. Results of studies on robotic splints.

Author	Number of Participants	Design (RCT, single group, pilot or feasibility)	Outcome measures	Results	Group Assignment
Yurkewich, Kozak, Hebert, Wang, & Mihailidis, 2020	11	Single Group study	Chedoke Hand and Arm Inventory, index finger extension, water bottle grasp and manipulation task, range of motion, grip strength, and pinch force	statistically significant improvements in a water bottle grasp and manipulation task, index finger extension, range of motion, grip strength, and pinch force while wearing glove compared to when not wearing glove.	
Villafañe et al., 2018	32	Randomized Controlled Trial study	National Institutes of Health Stroke Scale (NIHSS), Modified Ashworth Scale, Barthel Index (BI), Motricity Index (MI), QuickDASH, and visual analog scale (VAS)	Greater pain reduction, increase in functional ability, and significant improvement in VAS score compared to control.	Experimental Group: 15 Half hour therapy sessions with Gloreha Robotic Glove Control Group: 15 half hour sessions that included assisted stretching, shoulder and arm exercises, and functional reaching tasks.
Vanoglio et al., 2017	30	Randomized Controlled Pilot Study	MI, NHPT, Grip and Pinch Test	Significant improvement in MI, NHPT, Grip and pinch test scores compared to control	Experimental group: 30 40-minute therapy sessions with Gloreha Robotic Glove

					Control Group: 30 40-minute therapy sessions where the individuals' affected hands were moved passively by a physical therapist
Orihuela-Espina et al., 2015	17	Randomized Control Trial Study	FMA, MI	Significant improvement in FMA compared to control, no significant difference between MI scores in robotic and control treatments.	Experimental Group: 40 sessions of Robot active assisted therapy Control Group: 40 sessions of classical occupational therapy

Discussion

While static splinting has been one of the most popular methods of splinting in order to improve hand mobility after stroke, the evidence backing its efficacy is mixed. Many studies have shown that participants often experience pain or discomfort while wearing the orthosis, limiting its efficacy. Moreover, as static splints immobilize the hand, as opposed to dynamic or robotic splints, users are unable to perform activities or exercise their affected hand while wearing the splint. Dynamic splints, on the other hand, are generally shown to be effective at improving range of motion, dexterity, and grip and finger strength. Individuals can perform activities and exercises while wearing a dynamic splint, which encourages functional recovery. Importantly, dynamic splints do not cause as much discomfort as static splints and are generally affordable. However, the research on dynamic splints and their efficacy is limited. Further studies are needed to better understand how to use dynamic splinting in post stroke upper limb recovery. One area of future studies on both static and dynamic splinting could investigate is the topic of static progressive and dynamic progressive splinting (splints where tension on the muscle tissue is increased at set intervals), as they often show positive outcomes, but research is lacking.

Robotic splints are the latest development in rehabilitation technology. There are many benefits that have been observed from using robotic orthoses, such as the ability to have longer, more intense therapy sessions. Therapists can see more patients, as robotic splints allow individuals to complete automated therapy sessions at home. Many robotic orthoses also come with preprogrammed games and activities, making therapy more exciting and engaging. For example, robotic orthoses can track progress and adjust treatment plans based on patient progress and activities. Many studies show that robotic splints are effective at improving range of motion, grip, and pinch strength, and much more. However, the number of studies conducted on hand rehabilitation robots is insufficient, as many studies focus on robotic devices treating other limbs (Yue, Zhang, & Wang, 2017). Moreover, many studies do not evaluate the design of hand rehabilitation robots. Robotic orthoses are also highly expensive when compared to static and dynamic splints, with the average device costing around $5,000 (Wagner et al., 2011). More studies need to be done in order to evaluate hand rehabilitation robots, with more attention paid to the efficacy of the different designs. Table 4 summarizes the pros and cons of each type of splint.

Table 4. Comparison among the types of splints.

	Pros	Cons
Static Splints	-Popular and inexpensive - Increase range of motion and grip strength	-Individuals often complain of pain and discomfort. -Splints not worn for the prescribed amount of time -Evidence in favor of the efficacy of static splints is relatively weak
Dynamic Splints	-Dynamic Splints allow individuals to perform exercise and daily activities. -Consistently shown to improve range of motion, dexterity, and grip and finger strength. -More comfortable compared to static splints.	-Dynamic splints are often costly compared to static splints
Robotic Splints	-Allow for longer, more intense therapy sessions compared to non-robotic orthoses -Robots can track progress suggest individualized therapy plans -More rehabilitation can be done at home, allowing therapists to see more patients -Can assist in performing functional everyday activities outside of therapy/exercise.	-Often extremely expensive, with an average cost of $5152 (Wagner et al., 2011). This is far more expensive than static or dynamic splints.

Conclusion

Based on the research reviewed above, splints that allow the users to perform exercises and ADLs typically resulted in better outcomes (e.g., more significant improvement in range of motion, grip and finger strength, and ability to perform tasks) compared to static splints. While dynamic and robotic splints have shown to be generally effective at improving hand and upper limb function after stroke, more studies involving a larger sample size would yield a more complete picture of their efficacy. Furthermore, as robotic technology and artificial intelligence continue to progress, the price of robotic splints will likely come down. This will allow more individuals to access robotic splinting as a rehabilitation modality or assistive device.

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