Introduction

When patients experience hemiparesis after stroke, they generally have limited range of motion (ROM) due to upper limb muscle weakness and reduced hand function Kogler GF et al (2002), and have problems in functional activities due to neurological and non-neurological changes related with motor control Dietz, V et al (2007). These changes consequently result in the limitation of upper limb joint ROM or muscle shortening Foran JR (2005), O’Dwyer, N. J et al (1996) and are associated with spasticity, causing the reduction of hand functions such as stretching, grabbing, manipulating, and releasing R. Boyd et al (2001). Also, patients have impairment of activities of daily living (ADLs) due to spasticity, pain, and edema, and disfigurement of body image may be caused. It has been known that patients experiencing physical changes like these experience psychological disorders such as depression Robinson RG (1983), Pizzi A (2005), Burge E et al (2008) or decreased quality of life Delcourt C et al (2010). From this perspective, not only improving upper
limb function and spasticity prevention and treatment but also postural control and alignment, muscle stretching and improving joint ROM are significant goals for treatment Elovic E et al (2005).

The most commonly used rehabilitation program to enhance upper limb function, prevent spasticity and improve joint ROM is hand splint intervention. Its purpose includes spasticity reduction, prevention of muscle contracture, enhancement of functional motions, pain reduction, stretching shortened muscle and edema prevention Williams Pedretti L (1996), Milazzo S (1998), Wilton JC et al (1997). However, splint application has still been historically debated among rehabilitation specialists Edwards S et al (1996). This is due to lack of scientific evidence of splint application McPherson JJ et al (1982). Nevertheless, splint application is often used clinically for the treatment of upper limbs of patients with hemiparesis Kogler GF et al (2002). The evidence of clinical effort to reduce spasticity as well as muscle contracture by applying resting hand splint is that it is possible through applying low-load intensity to hypertonic muscle in a fixed posture or prolonged stretching. The purpose of stretching is to reduce spasticity by inhibiting the activation of reflexive alpha motor neuron and blocking a major cause of spasticity and contracture Gracies J M et al (2005). Also, plasticity is promoted by fixing the length of loosened muscle in that condition and accordingly contracture reduction can be achieved Kottke F J et al (1996). Therefore, it has been reported that applying resting hand splint results in the reduction of stiffness and improvement of joint ROM, and the extent varies by application period and measurement method Sheehan J L et al (2006). Also, it has been reported that applying resting hand splint for longer than 90 minutes daily has the effects of not only improving wrist ROM or spasticity reduction but also the reduction of pain or spasm Pizzi A et al (2005).

Unlike this, there is a report that the improvement of wrist ROM, pain and upper limb function have not been observed although resting hand splint has been applied to the wrist without active motion or the reduction of finger contracture Lannin NA et al (2007). Also, effects were not observed in the study with a group of wrist neutral posture, a group of wrist extension at 45°, and a control group Lannin NA et al (2003). From this perspective, there is even an argument that it is inappropriate to apply hand splint clinically Lannin NA et al (2003). However, because hand splint can be applied not only to volar but also the dorsal of hands, it is possible to argue that the effects can vary depending on a type Pitts DG (2008), Lannin NA et al (2003). It has been argued that volar resting hand splint is effective to support hypotonic wrist and a hand, and dorsal resting hand splint provides proper dorsiflexion to wrist and fingers and thus is more effective in treating hypertonic upper limb McCollough NC et al (1978). Some studies have reported that two types of splint - dorsal resting hand splint and volar resting hand splint - are effective in spasticity reduction, and most commonly used clinically McPherson JJ (1952), Rose V et al (1987).

The effects of resting hand splint can be explained two theories – biomechanical and neurophysiological theories Burge E (2008), Lannin NA et al (2003). The biomechanical theory is based on the effect of the extensive changes of muscle and connective tissues caused by mechanical force, and the neurophysiological theory is about the effect of spasticity reduction through the inhibition of reflex muscle contraction Gossman MR (1982), Langlois S et al (1987). Applying dorsal resting and splint and volar resting hand splint by a neurophysiological mechanism has been discussed. Some clinicians argue that dorsal resting and splint is more effective because it is supposed that spasticity increases due to the stimulation of hand flexor muscles by volar resting hand splint Lannin NA (2003), Langlois S et al (1989). However, from another perspective, both dorsal resting and splint and volar resting hand splint require the contact to the skin surface of the dorsal of the hand and
volar. Also, there is a study having reported that hand flexor muscle contraction reflex can be induced by skin stimulation due to the forearm to fix dorsal resting and splint and the finger fixing strap Shah S et al (2007).

Like this, in order to evaluate the therapeutic effect according to the types of resting hand splints, particularly the effect of the application of resting hand splint, more strict design is necessary. The effect can vary depending on the degree of a patient's recovery from stroke or application time & period Neuhaus B et al (1981) and the characteristics of upper limbs Kuipers K et al (2012). From this perspective, it is necessary to compare the effects of each type of resting hand splint including patients' characteristics, which have not been considered in previous studies.

**Literature Review**

The prognosis of upper limb functional recovery in stroke patients is generally poor McCollough NC et al (1978), and upper limb function is not proper in greater than 50% Broeks JG et al (1999). Therefore, the maintenance and prevention of joint ROM is essential for ADLs, particularly putting on clothes. Contracture of stroke patients generally occurs in wrists or ankles Pandyan AD et al (2003), and because functional activities decrease due to spasticity increase, pain induction, and limited motion resulted from wrist contracture McCollough NC et al (1978), postural alignment of joints, joint ROM exercise, and applying resting hand splint are essential for the prevention of contracture Lannin N A (2007). Although the effect of resting hand splint was based on the biomechanical approach until 1950, it is based on the neurophysiological approach to increase the recognition of proprioception by focusing on maintaining right joint posture and muscle extension for the reduction of hypertonicity as well as promotion of normal motion since the cause(s) of spasticity has been identified after 1950’s Neuhaus B et al (1981). Therefore, this study was designed to investigate the effect of the application of resting hand splint to stroke hemiparesis patients on spasticity and hand functions through the evaluations such as MAS, wrist AROM, and wrist sEMG.

In a previous study, the positive effect of spasticity reduction by applying resting hand – dorsal and volar-splints in stroke patients was not observed, and there was methodological limitation because the sample size was small as 10 subjects McPherson JJ et al (1982). According to the study about the significance of the period of resting hand splint application, the effect of resting hand splint on spasticity reduction in stroke patients was partially significant as of the 8th week Pizzi A et al (2005). In other studies, the positive effect of spasticity reduction was not obtained as two types of resting hand splint were applied for 4 weeks Lannin et al (2007), and a 4-week intervention period was insufficient for muscle extension and more time to reduce resistance was necessary Basaran A et al (2012).

In the result of wrist MAS in this study, significant reduction was shown in the group of dorsal resting hand splint. A randomized controlled trial was performed in a total of 52 subjects, and it was supposed that the number of subjects to ensure the effect size as well as the application for 6~8 hours daily for 8 weeks had influence. Also, the wrist extension angle of splint, that is, the extension load of hand flexor muscles affects spasticity Shah S et al (2007). The effect of spasticity reduction was obtained by applying the resting hand splint with low-load extension intensity, which was manufactured according to the structure and characteristics of a subject’s hand Pizzi A et al (2005). In this study also, spasticity reduction was obtained by applying the comfortable splint that was manufactured according to low-load extension and characteristics based on the degree of subjects' spasticity. However, there was no significant difference in the group with volar resting hand splint. As volar resting hand splint is mostly in contact with the skin surface of volar, there may be association
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with previous study results that spasticity can increase even more because of the stimulation of the extension reflex receptor of hand flexor muscles Langlois S et al (1989), and the clinical purpose to stabilize hypotonic upper limbs is greater McCollough NC et al (1978).

The results of wrist AROM and sEMG in this study proved significant effects in the group of dorsal resting hand splint. In the group of volar resting hand splint, wrist AROM did not show significant increase but there was significant activation of extensor muscle in wrist sEMG. It has been discussed that the measuring equipment for the effect of hand splint application in stroke patients needs to be determined by scientific and electrophysiological equipment rather than clinical findings or common ideas Gracies JM et al (2000). Supposedly it was because that the reliability of study results increased by measuring using the surface EMG with high reliability (DataLOG MWX8) and electrogoniometer in this study.

Resting hand splint is provided for the re-education of hand and upper limb functions Pitts DG et al (2008). Also, joint deformity is prevented, and extrinsic and intrinsic hand muscles as well as extensor and flexor muscles can be changed through the length-tension relationship of muscle. It has been reported that the splint manufactured according to the characteristics of a patient’s upper limb increases the stimulation of sensory-motor system, and can result in the maximum functional recovery through ROM increase and by maintaining function muscle length for gross motor and fine motor. In this study also, wrist AROM increased by spasticity reduction and changes of wrist muscle length in the group of dorsal resting hand splint, and increased joint ROM was supposed to have positive effects on improvement of hand functions.

The ability to maintain function wrist extension (about 10°∼30°) by the activities of wrist extensor muscles is essential in the production of great grip strength and hand dexterity Katz R et al (1989). Based on the result of this study, the wrist extension angle of resting hand splint was about 10°∼30°, and wrist AROM and the activation of extensor carpi radialis, which affect various functional hand activities, were measured.

The limitations in hand stretching, grabbing, and releasing generally occur due to the problem of extension function of hands and wrists after stroke Fayez ES et al (2013). This is manifested not only by the weakness of finger extensor muscles but also the stiffness and spasticity of flexor muscles of wrist or fingers. Also, limited grabbing is manifested as the weakness of finger flexor muscles as well as extensor carpi radialislongus and extensor carpi ulnaris Ruth Turk et al (2008). In the re-interpretation of this study result, motion is created by the interaction of agonistic muscle and antagonistic muscle, and because the stiffness and spasticity of wrist or finger flexor muscles work as an inhibitory factor of wrist active extension, reducing this inhibitory factor would have positive influence on wrist active extension. Also, it was discussed about the significant role of wrist extensor muscles in the functional activities of hands. This supports the results of this study and is expected to affect the improvement of hand functions for ADLs such as stretching, grabbing and releasing objects in the future by showing significant improvement in both groups for the activation changes of wrist extensor carpi radialis. However, there was no significant improvement in wrist AROM in the group of volar resting hand splint, indicating that there was no sufficient change of muscle activation to change joint ROM and it was probably affected by the spasticity of wrist flexor muscles.

Based on the result of this study, applying various types of resting hand splints would have positive influence in the improvement of hand functions. Resting hand splint is applied to joint ROM improvement, changes of motion quality, and functional improvement of upper limbs and hands Wilton JC et al (1997), and would have great effects in restoring social role(s) by helping the enhancement of ADLs
Applying resting hand splint to stroke patients would not only have preventive effects but also have great influence on the improvement of hand functions and consequently a greater goal of rehabilitation therapy, social return, in the future.

For the limitations of this study, it is challenging to generalize the study results because the number of previous studies about resting hand splint is insufficient. Also, supposedly the therapeutic effects were mixed because of the influence of early spontaneous recovery of brain damage as patients who developed stroke within 6 months were study subjects and the combination of traditional rehabilitation therapy. Also, the short study period of 8 weeks probably affected the study results. Further studies about more various splints to complement these limitations would bring valuable results.

Proposed Work

Study subjects

This study was performed in two groups, which were determined by random assignment according to the order of visits of 52 subjects who were diagnosed of stroke and disease period was 2-6 months among patients who visited K University Hospital located in Dongdaemun Gu, Seoul from February to April, 2015. Prior to beginning the study, voluntary subjects were recruited and provided with explanation of study purpose and contents, and a written consent form was obtained from the subjects who had strong desire to participate in the study. The sample size was calculated using G-Power program 3.1 Faul F et al (2009) for the t-test of two groups at the significance level 0.05, statistical power 0.8, and the effect size 0.8, resulting in a total of 52 for each group of 26 subjects. Cohen d defined the effect size; 0.2 was small, 0.5 was medium, and 0.8 was large. The inclusion and exclusion criteria were based on the previous study of Copley J et al. All experimental procedures were approved by the institutional review board (KHUHMDIRB 1501-01).

The Inclusion Criteria are as Follows:
First, adults over 19 years of age
Second, stroke (cerebral hemorrhage and cerebral infarction) patients who disease period was 2-6 months
Third, patients who can communicate and whose mini mental state exam-korean (MMSE-K) is ≥ 24
Fourth, people whose wrist modified ashworth scales (MAS): 1–2 grade
Fifth, people whose wrist manual muscle test (MMT): Trace-Fair grade
Sixth, people who have voluntarily consented to the purpose and methods of this study

The Exclusion Criteria are as Follows:
First, people with the contracture of muscle and soft tissue underneath the arm on the paralyzed side
Second, people with peripheral neuronal damage on the paralyzed side of upper limb and dermatological lesions
Third, people with severe pain on the paralyzed side of upper limb (visual analog scale ≥5)
Fourth, people taking antipasti medications
Fifth, people with cognitive and behavioral disabilities
The study design is shown in Figure 1.

Interventions

Types of Resting Hand Splints

The resting hand splints used in this study were two types – dorsaland volar - of splints. Two resting hand splints were manufactured based on the criteria suggested by Basaranet (2012) and Shah et al (2007).
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resting time and was repeated in reference of daytime/night in order to minimize the risk of muscle or skin damage, and subjects as well as their caregivers were educated about a proper method to apply. They were instructed to comply strictly with splint application through the daily checklist of splint application.

Conventional Rehabilitation Therapy

All study participants received occupational and physical therapies for 30 minutes daily 5 times a week. Occupational therapy is a therapy to restore physical functions to improve ADLs, and trainings of ADLs and upper limb muscles were performed using a variety of selected tools. For physical therapy, gait exercise, posture control training, joint ROM exercise, and muscle strengthening exercise were performed.

Evaluation and Evaluation Tools

Spasticity Test

(A) Modified Ashworth Scales (MAS)

Modified Ashworth Scale (MAS) was developed by Ashworth, and revised to 6 grades by Bohannon et al. 0: there is no muscle intensity or resistance increase. 1: A little resistance felt at the end of joint ROM by passive flexion of affected upper limb or extension. 1+: Resistance felt from ½ below the entire joint ROM. 2: Resistance felt in most joint ROM but movable. 3: Resistance felt to make passive movement challenging. 4: Infeasible movement within the joint ROM of flexion and extension. The test was performed while a subject was in supine position without moving upper limb, and the wrist joint was rapidly passively extended at completely flexed position by the force of the examiner. The degree of resistance that an examiner subjectively felt was graded Sloan RL (1992). This was repeated 4 times and the mean was used. Test-retest reliability was $r=.83$, and inter-rater reliability was high as $r=.84$ Gregson JM et al (1999).
statistics and Chi-Square test were used, and normality test was performed. For the homogeneity test prior to intervention in two groups, independent sample t-test was performed. For the difference in MAS, sEMG, and AROM before and after the intervention in two groups, paired t-test was performed, and independent sample t-test was performed to compare the change(s) before and after the intervention in two groups. Statistical significance level was α=.05.

Results

The general characteristics of the participants are described below. (Table 1)

Wrist MAS, wrist AROM, and Change(s) before and after the Intervention of Wrist sEMG in the Experimental Group (Table 2)

The wrist MAS, wrist AROM, and the change of wrist sEMG in the experimental group are shown in table 3. The MAS was grade 1.35±.629 in pre-test and grade .88±.711 in post-test (p<.01). The AROM was 8.73±8.879° in pre-test and 12.96±12.901° in post-test (p<.05).

Table 1. Characteristics of participants

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Experimental Group (n=26)</th>
<th>Control group (n=26)</th>
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<tbody>
<tr>
<td>Age(year), mean±SD</td>
<td>65.77±10.11</td>
<td>61.62±10.05</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>14/12</td>
<td>16/16</td>
</tr>
<tr>
<td>Type of stroke (Hemorrhage/Infarction)</td>
<td>7/19</td>
<td>8/18</td>
</tr>
<tr>
<td>Side of stroke (Right/Left)</td>
<td>11/15</td>
<td>9/17</td>
</tr>
<tr>
<td>Time since onset of stroke months, mean ± SD</td>
<td>3.38±1.49</td>
<td>3.54±1.42</td>
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</table>

SD: standard deviation.
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Table 2. Comparison of results between Experimental group and control group

<table>
<thead>
<tr>
<th></th>
<th>Experimental group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before treatment</td>
<td>After treatment</td>
</tr>
<tr>
<td>MAS (grade)</td>
<td>1.35 (0.629)</td>
<td>0.88 (0.711)†</td>
</tr>
<tr>
<td>AROM (angle)</td>
<td>8.73 (8.879)</td>
<td>12.96 (12.901)†</td>
</tr>
<tr>
<td>sEMG (mv)</td>
<td>0.028 (0.024)</td>
<td>0.037 (0.033)†</td>
</tr>
</tbody>
</table>

The values are mean ± standard deviation, MAS: Modified Ashworth Scale, AROM: Active Range Of Motion, sEMG: surface ElectroMyoGraphy.

†p<0.05 by Paired t test, †p<0.05 by Independent t test.

The sEMG was .028±.024mv in pre-test and .037±.033mv in post-test (p<.01), and there were significant improvements in all three tests as a result of analyzing before and after the intervention.

Wrist MAS, Wrist AROM, and Change(s) before and after the Intervention of Wrist sEMG in the Control Group (Table 2)

The wrist MAS, wrist AROM, and the change of wrist sEMG in the control group are shown in Table 4. The MAS was grade 1.38±.637 in pre-test and grade 1.19±.749 in post-test (p>.05). The AROM was 12.08±13.199° in pre-test and 12.85±13.199° in post-test (p>.05).

The sEMG was .038±.039mv in pre-test and .042±.041mv in post-test (p<.05). There was no significant difference in MAS and AROM as a result of analyzing before and after the intervention. However, sEMG showed a significant difference.

Comparison of the Changes of Wrist MAS, AROM, and sEMG between the Experimental and Control Groups (Table 2)

The comparison of the changes of wrist MAS, AROM, and sEMG between the experimental and control groups is presented in Table 5. The change of MAS was -.54±.647 in the experimental group, and -.15±.543 in the control group, showing a statistically significant difference (p<.05).

The change of AROM was 4.23±7.906° in the experimental group, and .77±2.388° in the control group, showing a statistically significant difference (p<.05). There was no significant difference in sEMG (p>.05).

Conclusion

This study was designed to investigate the effects of various resting hand splints for 8 weeks in stroke hemiparesis patients on the spasticity and hand function through wrist MAS, AROM, and sEMG. The study results are as follows.

First, there was a significant difference in wrist MAS, AROM, and sEMG in the group of dorsal resting hand splint.

Second, there was no significant difference in wrist MAS and AROM in the group of volar resting hand splint, but there was a significant difference in wrist sEMG.

Third, there was a significant difference in wrist MAS and AROM in the group of dorsal resting hand splint as a result of comparing change(s) between two groups, but there was no significant difference in wrist sEMG. Through this study, it was found that dorsal resting hand splint was more effective in the reduction of wrist spasticity and improving AROM than volar resting hand splint in stroke patients. Also, as there was a significant difference in wrist sEMG in both groups, it is expected that extensor muscle activation would increase.
hand function. Therefore, it is supposed to be an effective treatment for the hand function improvement of stroke patients. Finally, this would be able to contribute to the policy to reduce social burden by reducing medical fee of stroke patients.

References


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