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Original Article

Changes in the Range of Motion of the Hip Joint and the Muscle Activity of the Rectus Femoris and Biceps Femoris of Stroke Patients during Obstacles Crossing on the Ground and Underwater

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Abstract. [Purpose] The purpose of this study was to examine range of motion (ROM) and the muscle activity of stroke patients during obstacle task on the ground and underwater. [Subjects] The subjects of this study were seven stroke patients in a hospital located in Daejeon, South Korea. [Methods] The measurements in this study were conducted in an exercise therapy room and a pool dedicated to underwater exercise (water temperature 33.5 °C, air temperature 27 °C) in the hospital building. The pool's water depth was determined by considering the levels of the xiphoid process of the study subjects. Ten-centimeter-high obstacles were used. An electrogoniometer was used to examine the ROM of flexion and extension of the hip joints on the affected side. An MP150 system a BioNomadix 2-channel wireless EMG transmitter was used to examine the muscle activity of the rectus femoris and biceps femoris of the affected side. [Conclusion] The results suggest that the unaffected side was supported, that the affected side moved, and that the hip joint was bent more underwater than on the ground. The rectus femoris and bicpes femoris were activated significantly less underwater than on the ground in all sections.
Key words: Underwater obstacle, Stroke, Electromyography

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INTRODUCTION

Patients with hemiplegia due to stroke asymmetrically load their weight on their two lower limbs, have a reduced ability to move their center of gravity[1)], and show excessive muscle tone because of the disharmony between their agonist muscles and antagonist muscles resulting from the loss of ability to control their affected side. Among motor function disorders due to the abovementioned abnormal reactions, gait ability disorders cause patients to feel the most serious sense of loss[3)], because improvement and recovery of gaits are closely related to a patient's return to society and workplaces[2)].

Even if patients with hemiplegia due to stroke can walk in stable and controlled environments, their independent living will be limited if they cannot cross obstacles easily[4)]. If stroke patients try to cross obstacles unreasonably or cannot avoid crossing obstacles, their fall rates will increase. As a result, these patients tend to move their center of gravity toward their unaffected side due to their fear of falling, and they become passive in rehabilitation training due to these limitations and fears[5–9)]. In particular, although obstacle crossing requires larger movements of the hip joint because the body needs to be moved not just horizontally, but also vertically, hemiplegic patients are limited in their hip joint movements[10, 11)]. However, underwater training can not only reduce the fear of falling because it is safer than training on the ground and can be performed without any impact or injury while providing physical stability with buoyancy and fluid resistance but can also provide psychological stability so that patients can try it with confidence. Therefore, large positive effects can be expected from underwater training[12–14)]. Barela et al. advised that the peak of hip joint bending during the swing phase showed differences between training on the ground and underwater training, and Bates et al. reported that the hip joint was bent further during gait underwater[15)]. Given these studies, larger hip joint movements of stroke patients can be expected from underwater gait training.

However, the subjects of most previous studies were healthy, and some of the studies conducted with stroke patients measured movements during underwater training only, without comparing them with training on the ground. Also, these studies did not examine muscle activity and only examined gaits on stable surfaces.

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Therefore, the purpose of this study was to examine the hip joint range of motion (ROM) and muscle activity of the musculus rectus femoris and the musculus biceps femoris of stroke patients during obstacle crossing on the ground and underwater to present grounds for the effects of underwater exercise, thereby contributing to the development and advancement of underwater exercise programs in the future.

SUBJECTS AND METHODS

Subjects

The subjects of this study were seven stroke patients in a hospital located in Daejeon, South Korea. The study subjects were selected from among those who had a stroke at least six months earlier, could walk independently at least 10 m without any aids, had no internal medicinal or orthopedic problems or visual or auditory deficits, understood the purpose of this study, and had a firm voluntary intention to participate in the study. The subjects of this study consisted of three males and four females, and their mean age was 55.29±6.82 years. Their mean height was 167.43±6.75 cm, and their mean weight was 69.14±7.22 kg. Their mean elapsed time after stroke was 67.71±17.19 days, and their average Korea Mini-Mental State Examination (K-MMSE) score was 27.57±1.99 points. All of them were left hemiplegia patients and were right-handed. Before participation, they all signed an informed consent form that was approved by the local ethics committee of Eulji University.

Methods

The measurements in this study were conducted in an exercise therapy room and a pool dedicated to underwater exercise (water temperature 33.5 °C, air temperature 27 °C) in the hospital building. The pool's water depth was determined by considering the levels of the xiphoid process of the study subjects. An I-gym system (Isopa, Hwaseong, South Korea, 2010) composed of round towers, bars, and rings, which can form 10-cm-high obstacles, was used to create obstacles. The study subjects were instructed to cross these obstacles.

To check the study subjects' movements, the measuring process was videotaped using a digital camcorder (VPC CA-100, Sanyo Electric, Moriguchi, Japan, 2009). An electrogoniometer (Biometrics Ltd, Newport, UK, 2005) was used to examine the ROM of flexion and extension of the hip joints on the affected side. The sampling rate of the individual signals was set to 500 Hz. An MP150 system (Biopac Systems, Goleta, CA, USA, 2010) and a BioNomadix 2-channel wireless EMG transmitter (Biopac Systems, 2012) were used to examine the muscle activity of the musculus rectus femoris and musculus biceps femoris on the affected side using Ag-Ag/Cl (diameter 2 cm, Biopac Systems, 2012) electrodes. Electromyogram (EMG) signals were collected at a sampling rate of 1,000 Hz and processed by full-wave rectification. To process the data, the AcqKnowledge 4.1 (Biopac Systems, 2012) software was used to process the signals by conducting band-pass filtering at 30–500 Hz and notch filtering at 60 Hz to remove noise. The measured values are shown as the ratios of the individual measured values (RVC%, reference voluntary contraction) to the muscle activity value when the subject was standing upright on both feet on a stable surface on the ground. The electronic angle measuring instrument and wireless EMG transmitter were waterproofed using vinyl packs and medical waterproof tape and placed on the surface of the water. The electrodes attached to the skin were waterproofed using a modified and supplemented version of the method used by Silvers and Dolny[16].

The results of this study were processed using SPSS 20.0. Wilcoxon signed-rank tests were used to analyze the results in order to examine the differences between the exercises on the ground and underwater exercises; the significance level was set to $\alpha<0.05$. The measurement sections were divided as follows: 1) unaffected side lead (UL), 2) affected side trail (AT), 3) affected side lead (AL), and 4) unaffected side trail (UT).

RESULTS

As for the ROM of hip joint flexion and extension of the stroke patients on the ground and underwater, the ROM of hip joint flexion during the UL section underwater was smaller than that on the ground, but the difference was not significant ($p>0.05$). The ROM of the hip joint flexion during the UT section underwater was significantly smaller than that on the ground ($p<0.05$). The ROMs of the hip joint flexion during the AT and AL section underwater were significantly smaller than that on the ground ($p<0.05$).

During obstacle crossing by the stroke patients on the ground and underwater, the musculus rectus femoris was activated less underwater than on the ground in all sections, and the differences were significant during the UL and UT sections ($p<0.05$) but were not significant during the AT and AL sections ($p>0.05$). During obstacle crossing by the stroke patients on the ground and underwater, the musculus biceps femoris was activated significantly lesser underwater than on the ground in all sections ($p<0.05$) (Table 1).

DISCUSSION

Obstacle crossing is a task that requires a higher degrees of stable balance ability and control of the lower limb muscles, which makes it challenging and dangerous for stroke patients[4]. In particular, if stroke patients cross obstacles with support on the affected side, their speed will be reduced and their risk of falling will increase considerably, due to their unstable balance[17]. However, in underwater environments, even patients who are unable to stand under any weight loads can move using a small amount of power thanks to buoyancy and can experience diverse movement patterns that cannot be performed actively on the ground earlier, increasing the frequency of use of the affected and potentially inducing even more physical development[18–20]. Therefore, in underwater environments, obstacle crossing, which is a slightly more difficult task, can be applied to stroke patients.

In this study, during the AT and AL section, in which the unaffected side was supported and the affected side moved, the hip joint was bent more underwater than on the ground.

Table 1. Changes in the ROM of the hip joint and the muscle activity of the rectus femoris and biceps femoris during obstacle crossing on the ground and underwater (M±SD)

		Unaffected side lead	Affected side trail	Affected side lead	Unaffected side trail
Hip flexion-extension	Ground	−2.19±2.59[a)]	0.17±2.46	6.33±2.41	3.54±1.96
	Underwater	−3.72±2.31	11.63±1.94*	21.25±2.72*	0.61±2.67*
Rectus femoris	Ground	48.63±13.42	30.5±18.7	26.25±15.23	80.98±22.58
	Underwater	27.79±6.08*	24.93±5.40	14.26±2.74	30.67±5.69*
Biceps femoris	Ground	76.76±13.36	68.15±11.36	63.88±14.44	92.05±14.13
	Underwater	38.37±16.60*	50.82±13.74*	28.98±9.79*	31.59±17.67*

[a)]Positive values indicate flexion, and negative values indicate extension. *$p<0.05$

Masumoto et al. advised that underwater training would increase the activity of the hip joint flexor[21]. However, in this study, the musculus rectus femoris did not show any significant difference during the AT and AL section, between crossing obstacles on the ground and underwater. Jung et al. said that stroke patients' hip joints were bent more underwater because of buoyancy[22]. Since the lower limbs of healthy people sink in water because of their high specific gravity due to their large muscle mass, higher muscle activity is required underwater to move against the fluid resistance with lower limbs that would normally sink. However, the muscle mass and mineral densities of bones on the affected sides of stroke patients are reduced[23, 24]. These changes in these parts of the body, which have a higher specific gravity than water, combined with an increase in the amount of fat, which has a lower specific gravity than water, result in the patients' lower limbs being affected more by buoyancy[22]. Therefore, stroke patients' hip joints are thought to be bent more underwater as a result of support from buoyancy rather than the activity of the rectus femoris.

In this study, the rectus femoris was activated less underwater than on the ground during the UL and UT sections when the affected side was supported and the unaffected side moved so that the hip joint on the affected side was extended. Given this, the musculus rectus femoris is thought to have efferently contracted on the ground while the hip joint was extended so that it was more involved in stabilization of the lower limb on the affected side.

In this study, the musculus biceps femoris was less activated underwater than on the ground. In particular, the stroke patients moved their trunks forward more underwater than on the ground during the AL section so that the hip joint was bent more. Barela et al. suggested that the trunk is pushed forward during walking underwater in order to resist drag force[15]. The center of gravity of stroke patients is located relatively backward to limit their movements and reduce their risk of falling. The study subjects are thought to have been able to move their trunks forward more underwater because weight movements were easier and the support and drag force of the water prevented their weight from leaning forward.

In this study, during the transition from the AL section to the UT section on the ground, rapid forward movements of the trunk, which had been located relatively backward, were identified. Because of this, although the hip joint was bent more underwater than on the ground during the AL section, the hip joint was bent more on the ground than underwater. Therefore, the study subjects had wider strides underwater than on the ground. Said et al. described that if stroke patients had narrow strides after obstacle crossing, the base area would be reduced, and the risk of them losing their balance would increase such that their forward movements would be limited[25]. Therefore, stroke patients should be induced to have wide strides during obstacle crossing training underwater.

This study is thought to be quite meaningful because it examined the obstacle crossing of stroke patients underwater, which has not been sufficiently studied previously. However, interpretation of the results of this study was limited because the ROM of the hip joint was limited to flexion and extension and the muscle activities of the muscles that act for hip flexion and extension, such as the gluteus maximus and iliopsoas muscle, and back muscles and erector muscles of the spine related to trunk movements were not measured. If more diverse ROM and muscle activities are examined to figure out the movements of stroke patients' hip joints during obstacle crossing on the ground and underwater, more scientific grounds for underwater physical therapy can be presented and a large contribution can be made to the development and advancement of underwater exercise programs.

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