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Effects of Aquatic and Ground Obstacle Training on Balance and Muscle Activity in Patients With Chronic Stroke

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Abstract

Background: Obstacle training affects lower limb muscle activity, balance, reducing the risk of falls, and making gait more stable.

Objects: This study aimed to investigate the effects of aquatic and ground obstacle training on balance and muscle activity in patients with chronic stroke.

Methods: The study subjects included 30 patients with stroke, who were divided into aquatic (n_1= 15) and ground (n_2=15) groups. Groups underwent obstacle training three times per week, 30 min per session, for six weeks that went as follows: walking over sites with the paralyzed leg, stepping onto and down from a box step, and walking over obstacles with the non-paralyzed leg.

Results: The experimental results were obtained by comparing muscle activity. Activity of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius were significantly increased in the aquatic group ($p<.05$). Activity of the biceps femoris and tibialis anterior were significantly increased in the ground group ($p<.05$); however, the rectus femoris and gastrocnemius were not significantly different. In the comparison of maximal distance regarding the limits of stability, it was significantly increased on the non-affected side, affected side, and anterior and posterior distance in the aquatic group ($p<.05$). It was significantly increased in the non-affected side and anterior and posterior distance the ground group ($p<.05$); however, maximal distance on the affected side distance was not significantly different.

Conclusion: Gait training with aquatic and ground obstacles is effective for improving balance and gait ability of patients with stroke. However, it was more effective for the aquatic group than for the ground group.

Key Words: Aquatic therapy; Balance; Muscle activity; Stroke.

Introduction

Stroke severely restricts bodily movement owing to impairment in sensory and motor functions (Duncan et al, 2002). Particularly, compromised capacity to support the body and instability in weight bearing (Ikai et al, 2003) have an enormous impact on gait function and may cause secondary injuries owing to falls (Orlin et al, 2000).

A fall is when part of the body, other than a foot sole, touches the ground unintentionally. Falls reduce mobility, cause injuries, and generate fear of falls in strong patients (Teasell et al, 2002). Reportedly, 55% of patients with stroke experience one or more falls within a year of stroke onset, and 42% of these 55% patients experience multiple falls during that time (Ashburn et al, 2008). Accordingly, a plethora of exercise programs are conducted to prevent falls in patients with stroke. However, as research suggests that patients with stroke frequently fall owing to obstacles regularly encountered in everyday life, such as thresholds, doorsteps, curbstones, and bumpy ground, these aspects need to be studied (Austin et al, 1999).

Patients with stroke employ strategies to walk over obstacles that differ from normal, such as increasing vertical distance between the obstacle and the leading

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Table 1. General characteristics of the subjects (N=30)

	Aquatic group	Ground group	p-value
Gender (male/female)	9/6	10/5	
Age (year)	54.15±3.19[a]	56.07±5.31	.37
Height (㎝)	161.72±2.81	163.81±4.21	.57
Paretic side (right/left)	6/9	9/6	

[a]mean±standard deviation

leg to prevent a fall, reducing walking speed to provide a stable support to posture, and positioning the leg as close as possible to an obstacle (Chen et al, 1991). These factors suggest the need for ongoing gait training with environmental obstacles resembling the community setting. Accordingly, such gait training is usually provided on the ground (Miller et al, 2008), although patients with stroke tend to shift the center of the body to the non-paralyzed side and do not actively engage in gait training owing to fear of a fall (Melzer et al, 2008).

However, patients with stroke can be more active in gait training in water (Eich et al, 2004). This is because aquatic training provides a safer exercise environment by reducing the fear of falls and risk of injury (Hauer et al, 2002). Aquatic training increases stability because buoyancy offsets gravity, and the physiologic effects of lower heart rate and deeper breathing stabilize heart rate based on water depth (Noh et al, 2008). Because of its benefits, the aquatic environment has been incorporated into gait training, as demonstrated by the incorporation of aquatic therapy in programs to strengthen cardiovascular, neurologic, and skeletal muscular systems, including swimming exercise, aquarobics, training with floating devices, and walking over obstacles in water, in many countries such as the United States and Japan (Eyvaz et al, 2018).

Despite the numerous benefits of aquatic therapy, research has been limited to the Bad Ragaz Ring method, Halliwick, and Watsu interventions, and no studies have been published about gait training with obstacles in water. To propose a clinically effective intervention, this study investigated the effects of gait training with obstacles in water and on the ground on muscle activity and balance in the lower limbs in patients with chronic stroke.

Methods

Subjects

The study was conducted after the approval of the Institutional Review Board of Daegu University (approval number: 104061-201501-HR-022-02).

The study included 30 patients with hemiplegia and stroke diagnosed by computed tomography (CT) or magnetic resonance imaging (MRI), who had been hospitalized for >6 months and who provided voluntary consent to participate. Stroke onset had to be ≥ 6 months earlier to minimize the potential for spontaneous recovery, and patients had to have no fear of water and no aquatic training experience.

Inclusion criteria comprised unilateral brain injury identified by CT or MRI; ability to walk for ≥10 m with or without a walker; stiffness in the paralyzed lower limb of G2 or lower scores on the Modified Ashworth Scale; absence of orthopedic disease in both lower limbs; no restricted range of motion; and a score of ≥24 on the Mini Mental State Examination (Korean version), indicating ability to understand and comply with researchers' instructions. General characteristics of subjects are presented in Table 1.

Instruments

EMG equipment (TeleMyo DTS system, Noraxon Inc. USA) was used to analyze the surface muscle activity in four muscles: paralyzed rectus femoris, biceps

Figure 1. Obstacle training program (A: task 1, B: task 2, C: task 3).

femoris, tibialis anterior, and gastrocnemius. Electrode positions were the half point of a line connecting the anterior superior iliac spine and the superior patella (for the rectus femoris); the half point of a line connecting the ischial tuberosity and lateral epicondyle of the tibia (for the biceps femoris); two phalanges below the tibial tuberosity (for the tibialis anterior); and the third-point of a line connecting the fibular head and the heel (for the gastrocnemius). The standardization method was percent reference voluntary contraction (%RVC) (Stegeman et al, 2000). Measurement of the gait cycle was conducted by attaching a foot switch to the heel bone and the first metatarsus to activate the pressure sensor during walking.

Balance was measured using digital balance tester (BIO Rescue, RM Engineering Inc. France). This device measures the total area of moment of the center of pressure as the subject makes the maximum shift of the center of pressure by bearing body weight in eight directions (east, west, south, north, northeast, northwest, southeast, and southwest) as instructed on the front monitor. On the monitor, subjects watched a video and demonstration about how to shift weight. We measured the limit of stability in the standing position that allowed the maximum range of shift in the center of gravity while maintaining balance according to the direction displayed on the monitor.

Procedures

The 30 subjects were randomly assigned to aquatic and ground-training groups in equal numbers. All subjects received neurodevelopmental treatment five times a week, while participating in a 6-week, 30-min obstacle training program either in water or on the ground three times a week. The obstacle program comprised three tasks developed by modifying the techniques of Means & O'Sullivan (Means et al, 2000). Water and ground training included identical tasks with obstacle courses as follows: (Figure 1).

Task 1: Walking over obstacles with the paralyzed leg

Subjects walked over obstacles with the paralyzed leg as the leading leg and the non-paralyzed leg as the swinging leg in a 10-min walk with obstacles placed at 1-m intervals.

Task 2: Stepping on and down a box step

Subjects stepped onto a box step with the non-paralyzed leg first and then with the paralyzed leg; they then stepped down with the non-paralyzed leg first, followed by the paralyzed leg. Next, the sequence was reversed. Subjects continued stepping on and down for 10 min by switching the leading leg.

Task 3: Walking over obstacles with the non-paralyzed leg

Subjects walked over obstacles with the non-paralyzed leg as the leading leg and the paralyzed leg as the swinging leg in a 10-min walk with obstacles placed at 1-m intervals.

Statistical Analyses

Data analysis was performed using Statistical Package for the Social Sciences (SPSS ver. 18.0 for Windows) (IBMcorp., Armonk, NY, USA). Analyses included a paired t-test to examine the pretest-

Table 2. Comparison of muscle activation (N=30)

		Aquatic group	Ground group	*p*
Rectus femoris (%RVC)	Pre	522.54±284.50[a]	473.69±216.58	.04*
	Post	818.56±488.27	517.25±234.74	
	p-value	.01*	.40	
Biceps femoris (%RVC)	Pre	564.00±439.40	565.15±218.39	.04*
	Post	1078.59±569.96	708.53±336.01	
	p-value	.00*	.03*	
Tibialis anterior (%RVC)	Pre	1887.26±1191.88	1627.66±1019.94	.04*
	Post	2680.03±1487.86	1650.73±1024.14	
	p-value	.00*	.00*	
Gastrocnemius (%RVC)	Pre	531.27±626.79	437.84±387.62	.00*
	Post	807.33±195.29	481.35±228.18	
	p-value	.04*	.58	

[a]mean±standard deviation, *p<.05

Table 3. Comparison of limit of stability following standing (N=30)

		Aquatic group	Ground group	*p*
Non-Affected side (㎜)	Pre	2310.74±2028.51	2238.24±1321.91	.01*
	Post	3980.66±1537.65	2730.59±754.39	
	p-value	.00*	.02*	
Affected side (㎜)	Pre	1680.98±1521.85	1850.62±1447.41	.04*
	Post	3559.31±1764.57	2463.50±875.51	
	p-value	.00*	.13	
Forward (㎜)	Pre	2108.54±1215.44	2059.62±1126.65	.04*
	Post	3881.22±1379.71	2901.38±1101.65	
	p-value	.00*	.00*	
Backward (㎜)	Pre	2387.64±2445.27	2063.62±1175.85	.01*
	Post	4273.39±1802.89	2750.25±1276.03	
	p-value	.01*	.0*	

[a]mean±standard deviation, *p<.05

post-test difference within each group, and an independent t-test to determine the difference between groups. The significance level was set at p<.05.

Results

The aquatic-training group showed a statistically significant increase in muscle activity in the paralyzed rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius after training (p<.05). The ground-training group showed a statistically significant increase in muscle activity in the paralyzed biceps femoris and tibialis anterior after training but not in the paralyzed rectus femoris and gastrocnemius. Differences between the two groups were statistically significant for all four muscles (p<.05) (Table 2).

The aquatic-training group showed statistically significant increases in range of motion of the paralyzed and non-paralyzed sides and forward and backward movements after training (p<.05). The ground-training group showed statistically significant increases in range of motion of the non-paralyzed side and forward and backward movements but not of the paralyzed side. Differences between the two groups were statistically significant for all assessed ranges of motion ($p<.05$) (Table 3).

Discussion

This study compared ground and aquatic obstacle training to evaluate changes in muscle activity and balance in paralyzed leg muscles of patients with stroke; the idea was to improve understanding and facilitate provision of various gait training programs with a safer environment and training for fall prevention.

According to the study results, the aquatic-training group showed a significant increase in muscle activity in the rectus femoris, biceps femoris, and tibialis anterior in the paralyzed leg; however, the ground-training group showed a significant increase in muscle activity in the biceps femoris and tibialis anterior but not in the rectus femoris and gastrocnemius. This increased muscle activity was likely due to contraction and relaxation of lower limb protagonist and antagonist muscles to maintain posture during the unstable movements that patients with stroke made to go over obstacles. Watelain (2000) suggested that obstacle training increases muscle activity because sustained instability activates more muscles on the paralyzed side to support body weight and maintain stability of the trunk while utilizing more muscles to prevent the feet from dragging on the surface in a gait cycle between when the heel touches the ground and the stance phase. With the increased muscle activity due to obstacle training, the aquatic-training group outperformed the ground-training group. This between-group difference was likely due to greater resistance in water when moving the body and the existence of a center of buoyance apart from a center of gravity, requiring a greater level of muscle activity in the lower limbs to maintain posture of the trunk (Hakim et al, 2017).

This study investigated the effects of obstacle training on static balance by measuring changes in the limits of stability in the range of motion. The results showed a significant increase in range of motion of the paralyzed and non-paralyzed sides and forward and backward movements in the aquatic-training group. The ground-training group also had a significant increase in range of motion of the non-paralyzed side and forward and backward movements but not of the paralyzed side. However, the overall mean range of motion increased. The results suggest an improved limit of stability after obstacle training in patients with stroke. The obstacle training likely helped reorganization of the injured nervous system by affecting visual, vestibular, and somatosensory abilities that are responsible for balance. This also means that patients could better support their body weight with the paralyzed lower limb, suggesting the development of more stable support. Therefore, balance likely increased owing to improved proprioceptive sensitivity in the ankle joint or weight distribution. The positive effect of obstacle training was greater in the aquatic-training group than that in the ground-training group. Indeed, aquatic training is a more appropriate exercise environment for patients with stroke because they lack voluntary muscle contractions and are unable to properly control contraction timing and muscle activity. In aquatic training, the body weight is supported by buoyancy, which makes movement easier, including the movement of weak parts, and more balanced physical development can be expected (Matsumoto et al, 2016). Hemiplegia restricts movement in patients with stroke because they do not actively engage in tasks owing to fear of falls (Chu et al, 2004). Aquatic training outperformed ground training in our study likely because aquatic activity eliminates the fear of falls, keeps patients relaxed, and provides an environment where they can safely exercise.

Limitations of the study are as follows: first, the study conducted a global assessment of lower limb muscle activity rather than muscle activity for each phase of the gait cycle, which limits the specificity of assessment; second, the small sample limits generalizability of the study findings; and third, the study compared the effects of a 6-week intervention only; thus, owing to the lack of follow-up, it is unknown how long the training effect lasted. Therefore, future studies need to investigate the function of a greater number of muscles involved in walking and going over obstacles and need to include more patients in long-term programs involving diverse environments, including at home and in treatment rooms.

Conclusion

The study was conducted to determine the effects of obstacles training on the ground and in water on muscle activity in the paralyzed lower limb and balance in patients with stroke. While both groups showed improvement after training, muscle activity and balance improved more after aquatic training than after ground training. Thus, muscle activity and balance of patients with chronic stroke are more likely to benefit from obstacle training in water than from obstacle training on the ground.

References

Ashburn A, Hyndman D, Pickering R, et al. Predicting people with stroke at risk of falls. Age Ageing. 2008;37(3):270-276. http://doi.org/10.1093/ageing/afn066

Austin GP, Garrett GE, Bohannon RW. Kinematic analysis of obstacle clearance during locomotion. Gait Posture. 1999;10(2):109-120. http://doi.org/10.1016/s0966-6362(99)00022-3

Chen HC, Ashton-Miller JA, Alexander NB, et al. Stepping over obstacles: gait patterns of healthy young and old adults. J Gerontol. 1991;46(6):196-203. http://doi.org/10.1093/geronj/46.6.m196

Chu KS, Eng JJ, Dawson AS, et al. Water-based exercise for cardiovascular fitness in people with chronic stroke: a randomized controlled trial. Arch Phys Med Rehabil. 2004;85(6):870-874. http://doi.org/10.1016/ j.apmr.2003.11.001

Duncan PW, Horner RD, Reker DM, et al. Adherence to postacute rehabilitaion guidelines is associated with functional recovery in stroke. Stroke. 2002;33(1):167-177. http://doi.org/10.1161/hs0102.101014

Eich HJ, Mach H, Werner C, et al. Aerobic treadmill plus Bobath walking training improves walking in subacute stroke: A randomized controlled trial. Clin Rehabil. 2004;18(6):640-651. http://doi.org/10.1191/0269215504cr779oa

Eyvaz N, Dundar U, Yesil H. Effects of water-based and land-based exercises on walking and balance functions of patients with hemiplegia. NeuroRehabilitation. 2018;43(2):237-246. http://doi.org/10.3233/NRE-182422

Hakim RM, Ross MD, Runco W,et al. A community-based aquatic exercise program to improve endurance and mobility in adults with mild to moderate intellectual disability. J Exerc Rehabil. 2017;13(1):89-94. http://doi.org/10.12965/jer.1732838.419

Hauer K, Specht N, Schuler M, et al. Intensive physical training in geriatric patients after severe falls and hip surgery. Age Ageing. 2002:31(1):49-57. http://doi.org/10.1093/ageing/31.1.49

Ikai T, Kamikubo T, Takehara I, et al. Dynamic postural control in patients with hemiparesis. Am J Phys Med Rehabil. 2003;82(6):463-469.

Matsumoto S, Uema T, Ikeda K, et al. Effect of underwater exercise on lower-extremity function and quality of life in post-stroke patients: a pilot controlled clinical trial. J Altern Complement Med. 2016;22(8):635-641. http://doi.org/10.1089/acm.2015.0387

Means KM, O'Sullivan PS. Modifying a functional obstacle course to test balance and mobility in the community. J Rehabil Res Dev. 2000;37(5):

621-632.
Melzer I, Elbar O, Tsedek I, et al. A water-based training program that include perturbation exercises to improve stepping responses in older adults: study protocol for a randomized controlled cross-overtrial. BMC Geriatr. 2008;8:19. http://doi.org/10.1186/1471-2318-8-19
Miller EW, Combs SA, Fish C, et al. Running training after stroke: a single-subject report. Phys Ther. 2008;88(4):511-522. http://doi.org/10.2522/ptj.20050240
Noh DK, Lim JY, Shin HI, et al. The effect of aquatic therapy on postural balance and muscle strength in stroke survivors: A randomized controlled pilot trial. Clin Rehabil. 2008;22(10-11):966-976. http://doi.org/10.1177/0269215508091434
Orlin MN, Mcpoil TG. Plantar pressure assessment. Phys Ther. 2000;80(4):399-409. http://doi.org/10.1093/ptj/80.4.399
Stegeman DF, Blok JH, Hermens HJ, et al. Surface EMG models: Properties and applications. J Electromyogr Kinesiol. 2000;10(5):313-326. http://doi.org/10.1016/s1050-6411(00) 00023-7
Teasell R, McRae M, Foley NB, et al. The incidence and consequences of falls in stroke patients during inpatient rehabilitation: Factors associated with high risk. Arch Phys Med Rehabil. 2002;83(3):329-333. http://doi.org/10.1053/apmr.2002.29623
Watelain E, Barbier F, Allard P, et al. Gait pattern classification of healthy elderly men based on biomechanical data. Arch Phys Med Rehabil. 2000;81(5):579-586. http://doi.org/10.1016/s0003-9993(00)90038-8

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