Effect of backward walking training using an underwater treadmill on muscle strength, proprioception and gait ability in persons with stroke

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Objective: The purpose of this study was to investigate the effects of backward treadmill gait training between underwater and ground environments on strength, proprioception, and walking ability in persons with stroke.

Design: Randomized control trial.

Methods: Twenty eight subjects participated in the study in which they were randomly assigned to either the underwater backward treadmill training (UBTT) group (n=13) or the BTT group (n=15). In both groups, forward gait training was performed for 20 minutes on the ground treadmill. The UBTT group performed backward gait on an underwater treadmill for 20 minutes while the BTT group performed backward gait on a ground treadmill for 20 minutes. The gait training in each group was performed twice a week for a total of six weeks. Muscle strength, proprioception, and gait ability was assessed using a digital power meter, joint angle recurrence method using the smartphone protractor application, the Figure-of-Eight walk test (F8W) and the functional gait assessment (FGA) respectively.

Results: Both groups showed significant improvement in strength, F8W and FGA scores after training ($p<0.05$). However, there was no statistically significant difference between the two groups. Both groups showed significant improvement in proprioception after training ($p<0.05$). In the comparison between the two groups, there was a greater significant change in the UBTT group for joint proprioception ($p<0.05$).

Conclusions: In this study, it was found that both backward treadmill gait training programs were effective on strength, proprioception, and gait ability, and that underwater training was particularly effective on proprioception compared to ground training.

Key Words: Gait, Proprioception, Strength, Stroke

Introduction

Stroke is a representative chronic disease with symptoms of movement and sensory disorders that affect the consciousness, language, cognition, and also cause paralysis [1,2]. Among them, motor neurons and sensory nerve damage cause stroke patients to have difficulty in daily life due to problems in balance and walking [3]. The main causes of such gait disturbances are decreased muscle activity, lack of balance sense, and reduced weight-bearing capacity [4],

which limits the overall gait due to the slow gait cycle and reduced gait velocity [5]. Due to difficulties in performing daily life activities and requiring assistance, persons affected by stroke often exhibit low self-esteem, depression, and decreased quality of life [6].

Several studies have suggested various intervention methods to improve balance and walking ability for persons with stroke. Many studies have implemented treadmill gait training in patients with hemiplegia in order to improve postural symmetry by extending the weight support time [7] and

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through repetitive gait patterns [8], providing sensory input for promoting a normal gait pattern [9]. It has been reported that treadmill gait training with use of a harness promotes a more timely restoration in gait ability due to its ability to provide stability and its effectiveness in improving strength, balance, and control of gait patterns [10]. Backward gait training has been introduced as a functional gait training method due to its effect of reducing stress on the lower extremity, increasing muscle strength, and improving balance and gait ability. Even within stroke rehabilitation, backward gait training is being implemented because it is considered as a functional gait method [11].

Underwater, the load put onto the lower extremities is decreased and use of the water resistance is effective in improving muscle strength, endurance, equilibrium, and cardiopulmonary endurance [12]. After a stroke incident, the subsequent decrease in physical function makes it difficult to exercise safely and there is a higher risk of falls [13]. In addition to providing a safe training environment compared to underground therapy, aquatic exercises are effective because it also provides psychological stability [14]. Previous studies reported improved function in those who underwent underwater gait training [15], and improved walking ability with underwater gait training within the elderly population [16]. However, studies using functional backward gait training on an underwater treadmill have been conducted only in case studies on healthy children [17], or children with cerebral palsy [18]. Therefore, the purpose of this study was to investigate the effects of backward gait training on an underwater treadmill on strength, proprioception, balance and walking ability in persons with stroke and to compare the results with back gait training performed on a treadmill on the ground.

Methods

Participants

The subjects of this study were those diagnosed with stroke who had been admitted to a rehabilitation hospital located in Daejeon Metropolitan City.

The inclusion criteria included (1) those with an onset of stroke greater than six months but less than two years, (2) a score of greater than 24 on the Korean mini mental state examination (K-MMSE) [19], and (3) have the ability to perform backward walking on a treadmill independently with or without an orthosis at a speed of 0.8 km/h [20] for 20

minutes. The exclusion criteria included those who could not walk or were fearful of walking in an underwater environment, those who had an open skin wound or skin disease, and those with fecal incontinence.

A total of 30 subjects who have met the selection criteria were randomly assigned to either the underwater backward treadmill training (UBTT) group (n=15) or the BTT group (n=15). During the study, two subjects were discharged from the UBTT group, leaving a total of 13 persons who have participated in the UBTT group. This study was conducted with the approval of the Institutional Review Board of the Daejeon University (IRB No. 1040647-201706-HR-016-03).

Procedure

All subjects in this study were subjected to forward gait training at a rate of 1.0 m/sec for 20 minutes on the ground treadmill, and after a 15-minute rest period, the subjects who had been randomly assigned to either the UBTT group or the BTT group performed backward gait training for 20 minutes. Therefore, the total intervention time of the two groups was 40 minutes per session, twice a week for 6 weeks [21].

Underwater treadmill training group

The backward gait training on an underwater treadmill was performed for 20 minutes at a speed of 1.0 km/h with a safety bar placed on both sides of the treadmill and a water height of one meter, which was at the approximate height of the subject's waist. The speed of the treadmill was increased by 0.1 km/h every week after training. In order to ensure patient safety, the subject was within reach of a safety handle if necessary and a therapist stood next to the subject in the underwater condition (Figure 1A).

Backward treadmill training group

Backward gait training on a ground treadmill was performed with a harness in preparation for falls and the walking speed was set at 1.0 km/h for 20 minutes. The speed of the treadmill was increased by 0.1 km/h every week after training. In order to secure the safety of the patient, the patient wore a harness that promoted a non-weight-bearing state. Handles were available on both sides of the treadmill and a therapist was present at the side of the subject for patient safety (Figure 1B).

Figure 1. Backward treadmill training (A) on the underwater, (B) on ground.

Outcome measures

Muscle strength

Muscle strength was measured using a digital power meter (PowerTrack II Commander Hand-held Dynamometer; JTECH Medical, Midvale, UT, USA). This tool measures the muscle force for isometric movements and uses the unit Newton [22]. The muscle strength test was performed with the subject in side-lying position with the paretic side facing up. Hip and knee flexion and extension strength was assessed. To increase the reliability of the measurements, a single therapist had consistently conducted the muscle strength assessments. The instrument has a measurement reliability of 99% [20].

Proprioception

As one method of assessment of proprioception, the joint position sense was assessed with the joint angle recurrence method [23]. To display the correct angle, a smartphone protractor application (Protractor and Angle Gauge; Smart Tools Co., Daegu, Korea) was used [24]. The inter-rater reliability of the smartphone protractor application is high with an intra-class correlation coefficient (ICC) value of 0.76-0.95 [25]. The joint position sensory test was measured by an active-active reproduced test. Proprioception was

measured with the subject performing a one-legged stance on the unaffected side and using the affected side to achieve hip and knee flexion and extension up to a target angle within a range of 0 to 90 degrees. After a 10-second rest period, the subject was asked to actively perform hip and knee flexion and extension again up to the same target angle within five seconds. The error angle was calculated between the initial target joint angle and the range achieved the second time in order to assess the subject's degree of proprioception.

Assessment of gait ability

Figure-of-Eight walk test

The Figure-of-Eight walk test (F8W) was used to evaluate the subject's ability to be aware of his or her environment, the ability to walk in a curvilinear pattern required for daily walking, and also assess for potential fall risk [7]. In this test, the time taken to walk around two cones placed at 152 cm intervals was measured. The ICC value for intra-rater reliability was reported to be $r=0.85-0.92$ and the ICC for test-retest reliability was $r=0.84$ [7]. A total of three measurements were taken and the mean value was used.

Table 1. General characteristics of subjects (N=28)

Characteristic	Underwater backward treadmill training (n=13)	Backward treadmill training (n=15)	χ^2/t
Sex (m/f)	8/5	7/8	0.619
Age (yr)	49.46 (9.60)	57.40 (11.61)	-1.953
Height (cm)	169.08 (6.53)	163.53 (8.00)	1.989
Weight (kg)	67.31 (9.53)	64.07 (9.60)	0.895
Type (hemorrhage/infarction)	5/8	7/8	0.191
Paretic side (right/left)	5/8	7/8	0.191
Onset (mo)	16.15 (5.70)	18.13 (4.85)	-0.985
MMSE (score)	27.85 (0.99)	28.07 (0.88)	-0.619

Values are presented as only number or mean (SD).

Assessment of functional gait

Functional gait assessment

This assessment is composed of 10 items such as walking in a designated area, walking in a straight line, walking over a box, etc [26]. The total score ranges from 0 to 30 with each item consisting of a 0 to 3 point sequence scale. Each item is scored on a 0 to 3 scale where a score of 0 indicates severe disability or inability to perform while a score of three indicates complete ability to perform. The intra-rater reliability of the instrument was $r=0.92$, and the inter-rater reliability was $r=0.91$ [27].

Data and statistical analysis

All data was analysed using IBM SPSS Statistics ver. 20.0 (IBM Co., Armonk, NY, USA). The general characteristics of the subjects are expressed as mean and standard deviation values through descriptive statistics. The chi-square test and independent sample t-test confirmed the homogeneity between the groups. The Shapiro-Wilk test was used for the normality analysis of all variables. The UBTT and the BTT groups were compared using the paired t-test to compare before and after intervention, and the difference between groups was analysed with the independent t-test. The statistical significance level was set as $\alpha=0.05$.

Results

A total of 28 participants participated in this study and were randomly assigned to either the UBTT group (n=13) or the BTT group (n=15). There was no statistically significant

Table 2. Comparison of muscle strength (N=28)

Variable	Underwater backward treadmill training (n=13)	Backward treadmill training (n=15)	t
Hip flexion			
Pre-test	144.85 (26.94)	146.93 (24.78)	-0.212
Post-test	165.00 (33.35)	161.47 (29.09)	0.297
t	-5.480*	-4.890*	-
Change value	20.15 (13.25)	14.53 (12.52)	1.135
Hip extension			
Pre-test	121.39 (32.38)	125.81 (20.90)	-0.435
Post-test	144.92 (30.94)	141.40 (28.41)	0.312
t	-4.800*	-4.890*	-
Change value	23.53 (17.68)	15.59 (12.36)	1.393
Knee flexion			
Pre-test	71.44 (35.11)	72.53 (34.93)	-0.082
Post-test	87.19 (29.97)	84.39 (36.03)	0.224
t	-4.590*	-4.420*	-
Change value	15.75 (12.46)	11.85 (10.39)	0.902
Knee extension			
Pre-test	96.54 (29.73)	104.11 (29.54)	-0.674
Post-test	119.62 (28.08)	117.59 (29.22)	0.187
t	-4.600*	-5.570*	-
Change value	23.08 (18.09)	13.48 (9.23)	1.180

Values are presented as mean (SD).

* $p<0.05$.

difference in sex, age, height, weight, type, paralysis, duration of disease, and MMSE scores between the two groups ($p>0.05$; Table 1).

For the muscle strength test, there was a significant improvement in both the UBTT and BTT group in hip flexion, extension, and knee flexion and extensor muscle strength before and after intervention ($p<0.05$). There was no significant difference between two groups ($p>0.05$; Table 2).

In the position sense test, both training groups showed significant improvement in hip and knee joint proprioception after intervention ($p<0.05$). There was a significant improvement in hip and knee flexion joint proprioception in the underwater compared to the ground training group ($p<0.05$; Table 3).

In order to investigate walking ability, the F8W and functional gait assessment (FGA) were compared before and after intervention for each group. There was a significant improvement in F8W and FGA scores in the UBTT group and BTT group ($p<0.05$). However, there was no significant difference between the two groups ($p>0.05$; Table 4).

Table 3. Comparison of proprioception (N=28)

Variable	Underwater backward treadmill training (n=13)	Backward treadmill training (n=15)	t
Hip flexion			
Pre-test	4.49 (1.69)	5.89 (2.52)	-1.648
Post-test	3.12 (1.47)	5.24 (2.60)	-2.599*
t	9.794*	5.241*	
Change value	-1.38 (0.51)	-0.65 (0.48)	-3.904*
Hip extension			
Pre-test	4.51 (1.96)	5.83 (2.41)	-1.605
Post-test	3.29 (1.90)	5.15 (2.56)	-2.076*
t	12.042*	3.978*	
Change value	-1.15 (0.35)	-0.69 (0.67)	-2.267*
Knee flexion			
Pre-test	4.27 (2.33)	3.83 (2.97)	0.325
Post-test	3.29 (2.00)	3.49 (2.85)	-0.870
t	4.617*	5.030*	
Change value	-0.98 (0.76)	-0.35 (0.27)	-3.081*
Knee extension			
Pre-test	2.95 (2.28)	3.95 (1.68)	-1.325
Post-test	2.32 (1.96)	3.54 (1.57)	-1.870
t	3.007*	5.190*	
Change value	-0.63 (0.77)	-0.41 (0.30)	-1.081

Values are presented as mean (SD).
* $p < 0.05$.

Discussion

The purpose of this study was to investigate the effect of backward treadmill training underwater on strength, proprioceptive sensation, balance, and walking ability and to compare with ground treadmill training.

The results of this study showed that there was a significant improvement in muscle strength in both the UBTT and BTT groups after intervention ($p < 0.05$), but the difference between before and after intervention was not significant ($p > 0.05$). Walking backwards on the ground can minimize stress applied to the knee joint due to the eccentric contraction of the knee joint during the deceleration period and increase the muscle strength by the isometric and afferent contraction of the knee joint during the support phase [28]. In the beginning of the backward gait training, an increase in hip and knee joint flexion and extension proprioception has been observed as well as an increase in muscle activity, which has been reported to have a positive effect on the improvement of muscle strength compared with forward gait [29]. The effect of underwater training is due to the fact that

Table 4. Comparison of gait ability (N=28)

Variable	Underwater backward treadmill training (n=13)	Backward treadmill training (n=15)	t
Figure-of-Eight walk test			
Pre-test	14.42 (5.74)	17.26 (9.71)	-0.992
Post-test	12.95 (4.66)	16.23 (8.82)	-1.201
t	3.980*	2.801*	
Change value	-1.47 (1.34)	-1.03 (1.43)	-0.842
Functional gait assessment			
Pre-test	19.85 (4.49)	17.20 (6.9)	1.182
Post-test	22.08 (4.94)	18.53 (6.4)	1.620
t	-4.624*	-4.183*	
Change value	2.23 (1.74)	1.33 (1.23)	1.591

Values are presented as mean (SD).
* $p < 0.05$.

water resistance acts on the movement of the lower limb during walking in the aquatic environment, thus producing a positive enhancement in muscle strength [30]. However, with an aquatic environment, since there is less weight load put onto the body due to buoyancy of the water it is considered that significant changes in muscle strength are less with aquatic training compared with ground training.

Proprioceptive sensory change was significantly improved both in the underwater and ground training group after intervention ($p < 0.05$), and a significant change in hip and knee flexion and extension was observed after intervention ($p < 0.05$). Significant differences in joint position sensation in the training group after intervention may be due to exercise being performed on an unstable support surface as a way to potentially change the neural network mobilization, and therefore, promote balance [31]. For this reason, the fluctuation caused by the water flow may serve as a similar situation to use of an unstable support surface, which promotes postural control and dynamic balance control of the subject, which is considered to enhance the joint position sense.

To investigate the improvement of walking ability, the F8W and the FGA tests were used for evaluation. In the UBTT and the BTT groups, the F8W and the FGA scores showed significant changes before and after the intervention ($p < 0.05$). However, there was no significant difference between the two groups after intervention ($p > 0.05$). In previous studies, there was a significant improvement in gait velocity, gait, and gait symmetry with use of backward gait training performed by twenty-five patients with stroke for

three weeks [32], and in nine patients with stroke, there was a significant improvement in functional walking ability [33]. Training in the aquatic environment has the effect of improving muscle strength and enhancing the balance ability by stimulating the intrinsic receptors [34]. According to this study, it is considered that backward gait training is effective in improving gait ability.

The limitation of this study is that the water level was not taken into account for each subject during the underwater training and thus the water buoyancy level was not controlled equally. However, considering the height range of all subjects, the water level was at the height of the waist for the majority of the subjects, thus supporting 50%-60% of the body.

According to this study, backward gait training on an underwater treadmill as an exercise method is effective in improving proprioceptive sense in persons with stroke. These results suggest that the application of backward underwater treadmill training should be used to take advantage of buoyancy for fall prevention and applied for the purpose of producing functional improvement in persons with stroke.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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