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Effects of Underwater Treadmill Gait Training on Gait, Balance, and Pulmonary Function in Stroke Patients

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Abstract

The purpose of this study was to compare the effects of underwater treadmill gait training (UTGT) and overground treadmill gait training (OTGT) on the gait, balance ability and pulmonary function of stroke patients. Twenty subjects were recruited for this study. The subjects were randomly assigned to two groups: UTGT (n_1=10) and OTGT (n_2=10). The 10 m walk test (10 MWT), Berg Balance Scale, Timed Up and Go (TUG) test, center of pressure, pulmonary function of forced vital capacity (FVC), forced expiratory volume after 1 sec (FEV1) and FEV1/FVC were measured before and after 4 weeks of training. Both groups undertook the gait training for 30 min a day, 3 times a week, for 4 weeks, and rating of perceived exertion of the groups were measured and compared. All the studied variables were significantly improved in both groups ($p<.05$) at the end of the study, except in the FEV1 of OTGT ($p>.05$). There was significant between-group difference in all of the variables, except in the 10 MWT ($p>.05$). These findings suggest that UTGT is more effective than OTGT in improving the balance and pulmonary functions of stroke patients.

Key Words: Balance; Gait training; Pulmonary function; Stroke; Underwater treadmill.

Introduction

Stroke causes damage to motor and sensory nerves. Such damage induces functional disorders in stroke patients, including gait disturbances (Williams et al, 1999). Among stroke patients, 75% can walk independently, but 50% of them still have gait disturbances (Hyndman et al, 2002). Reduced muscles activity, difficulty in weight shift, and a decline in balance functions due to degraded proprioceptive senses mainly cause gait disturbances. Compared to healthy individuals, stroke patients show reduced mobility and stability and different gait patterns, resulting in increased energy costs and limited gait endurance (Patterson et al, 2007). In addition, compensated motor patterns, such as circumduction gaits are found in stroke patients (Gillen, 2010; Kim and Eng, 2003; Roth et al, 1997).

Balance is an ability to maintatin the line of gravity of a body withing the base of support with minimal postural sway (Shumway-Cook et al, 1988). For maintaining balance need to visual feedback, vestibular and proprioceptive sense (Pollock et al, 2000). Stroke patients have decrease control mobility, weak muscle power and hemianesthesia that affect balance problems. They have been implicated in the poor recovery of activities of daily living (ADL) and mobility and an increased risk of falls. Thus Stroke patients are necessary to improve balance ability for functional mobility, stability and ADL (Tyson et al, 2006).

Stroke patients may also exhibit breathing disorders, with breathing problems due to the weakening of the diaphragm, the intercostal muscles, and the abdominal muscles (Lanini et al, 2003). Stroke patients with neuromuscular system disease are unable to take deep breaths at regular intervals. The decreased breathing ability reduces physical abilities, functional mobility, and independent gait ability (Kang,

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2003). Independent gait ability is an important element in quality of life and participation in daily living. In rehabilitation treatment, it is one of the most important abilities to improve for a return to daily living (Flansbjer et al, 2005; Lord et al, 2004). According to previous studies, appropriate rehabilitation exercises for pulmonary functions should be included in the rehabilitation treatment of stroke patients.

Overground treadmill gait training (OTGT) is gait training using mechanical assistance, such as a harness or belt. With practice, OTGT improves the timing of the lower extremity during gaits to increase the extension of the hip joint during stance phases. Changes in gait patterns contribute to improvements in the symmetry of gaits (Ada et al, 2003; Harris-Love et al 2001). Providing positive feedback to a patient taking part in OTGT can improve a patient's spirits and motivate the patient to feel more confident about walking (Moore et al, 2010). In addition, OTGT can strengthen the lower extremity muscles and improve gait velocity, gait endurance, and cardiopulmonary functions (Macko et al, 2001; Silver et al, 2000).

Underwater treadmill gait training (UTGT) is similar to OTGT in terms of body support, but it enables gait training with reduced weight using the buoyancy of water (Simmons and Hansen, 1996). Water has various physical characteristics, such as buoyancy, hydrostatic pressure, and viscosity that affect the human body (Becker, 2009). In OTGT, the patient has to wear a harness or belt for weight bearing. This is not necessary in UTGT where the water assists the stroke patient's balance ability. Furthermore, training in water reduces the patient's fear of falling and aids their sense of stability (Jung et al, 2010). A previous study that compared UTGT and OTGT implemented at the same velocity reported that the gait patterns and muscle strength of the UTGT group improved to a greater extent than those of the OTGT group (Park et al, 2012). As recent study investigated the effects of UTGT on the peak torque of the knee in stroke patients, UTGT showed an increase in the peak knee extension torque (Lee et al, 2015). In addition, Aquatic exercise showed that to enhance the balance and decrease the depression of stroke patients (Kim et al, 2014). UTGT in adults with osteoarthritis was more effective than OTGT for improving balance ability (Bressel et al, 2014). Water immersion and UTGT may reduce the workload of the cardiovascular system. The mean maximum increases in blood pressure, heart rate and the rate pressure product of UTGT were significantly lower than that of OTGT (Yoo et al, 2014). In another study, the metabolic costs and the heart rates and rating of perceived exertion (RPE) scores of the UTGT group were higher than those of the UTGT group at the same stride length (Masumoto et al, 2013).

In rehabilitation treatment, underwater exercises are attracting increased attention. However, there are limited studies of UTGT among stroke patients and even fewer studies of the effects of UTGT on stroke patient's balance and pulmonary functions. In addition, earlier studies had used velocity-based indicators which were objective and did not consider subjective issues, such as a patient's psychological stability or the environment. In the our study, we hypothesized that UTGT would be more effective than OTGT in improving the gait, balance, and pulmonary function of stroke patients. To test this hypothesis, we examined differences in the effects of UTGT and OTGT on stroke patients' balance, gaits, and pulmonary functions at the same exercise intensity according to the patients' RPE scores.

Methods

Subjects

The study consisted of 20 stroke patients with gait disturbances and poor respiratory function in D Hospital in Daejeon. All of the protocols used in this study were approved by the University of Daejeon. The participant's rights were protected according to the guidelines of the University of Daejeon (approval number: 1040647-201506-HR-031-03). The subjects sufficiently understood the explanations given about the purpose and method of the study and voluntarily agreed to take part in the study. The subjects were randomly assigned to an UTGT group (n_1=10) or an OTGT group (n_2=10). The inclusion criteria were subjects with heights in the range of 150～175 ㎝ who could independently walk for at least 10 m using a walking aid or under the supervision of a therapist, a score of less than 45 points on the Berg Balance Scale (BBS), no musculoskeletal disease or other neurological disease, and a score of 24 points or higher on the Korean version of Mini-Mental Status Examination for the measurement of RPE score according to the Borg scale. The intergroup characteristics of the 20 subjects in the UTGT group (n_1=10) and OTGT group (n_2=10) are shown in Table 1.

Measurement tools and methods

Rating perceived exertion (RPE)

To ensure the same exercise intensity in both the UTGT and OTGT groups, the patient's perceptions of their heart rates according to their RPE scores, newly modified by Borg and translated into Korean, were used. The RPE scale is an easy self-assessment measurement method of exertion that requires no direct physiological measurements of maximal oxygen uptake. A subjective rating of 13 points is equal to approximately 130 heart beats per min and an metabolic equivalent of 50% (Altenburger et al, 2013; Masumoto et al, 2008).

Assessment of gait ability: 10 m walk test (10 MWT)

To assess the patient's gait ability, the 10 m walk test (10 MWT) was used (Hunt et al, 1981). The 10 MWT, which measures the level of gait functions, has been shown to have high intrarater reliability (r=.89～1.00). In the tests, to reduce errors due to the acceleration and deceleration at the beginning and end of walking, each subject walked 14 m, and the time to walk 10 m excluding the 2 m each at the beginning and the end was measured (Dean et al, 2000).

Assessment of balance: Timed up and go (TUG) test

Timed Up and Go (TUG) tests were conducted to assess the patients' dynamic balance and gait ability. The assessment method consists of standing, walking 3 m, and returning to sit again. TUG test is usefully used for stroke patients with lower extremity disorders because the measuring method is not complicated and has been reported as having high validity and reliability (intra-class coefficient=.99) (Ng and Hui-Chan, 2005).

Assessment of balance: Berg balance scale (BBS)

The Berg Balance Scale (BBS) was used to measure functional gait ability in relation to balance. The BBS is an objective measure of static balance ability and dynamic balance ability and has high in-

Table 1. General characteristics of the subjects (N=20)

Variables	UTGT[a] (n_1=10)	OTGT[b] (n_2=10)	p
Gender (male/female)	4/6	6/4	.48
Affected side (left/right)	5/5	5/5	1.00
Age (year)	63.4±9.0[c]	64.9±10.0	.52
Height (㎝)	158.8±6.8	161.3±11.5	.39
Weight (㎏)	64.4±8.9	66.6±9.2	.48
BMI[d] (㎏/㎡)	17.8±4.3	19.9±6.5	.35
Onset time (month)	22.8±5.1	22.2±5.9	.63

[a]underwater treadmill gait training, [b]overground treadmill gait training, [c]mean±standard deviation, [d]body mass index.

tra-rater (r=.99) and inter-rater reliability (r=.98) (Berg et al, 1992).

Assessment of balance: Center of pressure

The limit of stability, which identifies dynamic balance control ability, measured using BioRescue (RM INGENIERIE, Rodez, France). BioRescue has a 610×580×10 ㎜ baropodometric platform equipped with 1,600 pressure sensors, which can be used to evaluate weight bearing, body movements, and balance between the left and the right lower limbs using pressure sensors under the feet. All the subjects were instructed to stand in an upright position and to keep their eyes forward. They were then instructed to move their center of pressure, following the arrow on the BioRescue screen. The average values of three measurements were used (Kim and Cha, 2015).

Assessment of pulmonary function

The forced vital capacity (FVC), forced expiratory volume after 1 sec (FEV1), and FEV1/FVC were measured using a spirometer (CHESTGRAPH HI-101, CHEST M.I. Inc., Tokyo, Japan). An interval of 5 min was given between each assessment. The FEV refers to the amount of air than can be maximally inhaled and exhaled, and the FEV1 refers to the volume of forced exhalation after 1 sec. The FEV1/FVC is the ratio of FEV in 1 sec to the FVC. The values were measured three times, and the average values were recorded. Restrictive pulmonary disease in stroke patients can be identified using these values. The FEV1/FVC provides an indirect assessment of the volume of the thorax and respiratory muscle strength (Kisner and Colby, 2007; Lee et al, 2011).

Intervention

Underwater treadmill gait training (UTGT)

The gait training was undertaken for 30 min on an underwater treadmill (Aqua Zone, SUNION, Hwaseong-si, Korea) (Figure 1). The water temperature was maintained at approximately 33 ℃, and the water depth was set to the depth at which the water filled the tank up to the area between the patient's xiphoid process and umbilicus. On the underwater treadmill, the subject walked at a comfortable speed at the beginning and increased the walking speed 5 min later to maintain an RPE score of 13 points. The RPE was continuously checked to adjust the speed for 20 min. The subject was instructed to maintain a comfortable speed for the last 5 min as a cooling-down exercise. A physical therapist observed to patients for safety (Brach et al, 2015).

Overground treadmill gait training (OTGT)

The OTGT was undertaken for 30 min using commonly used overground treadmill (T-5300, MAXTON, Gwangju-si, Korea). All subsequent protocols were the same as in the UTGT program (Brach et al, 2015).

Figure 1. Underwater treadmills (A) and underwater treadmill gait training (B).

Procedures

The subjects were randomly assigned to the experimental group (n_1=10, UTGT group) and the control group (n_2=10, OTGT group). Both groups underwent the interventions for 30 min per time, 3 times per week, for 4 weeks. An initial assessment was conducted before the intervention, and a final assessment was conducted 4 weeks.

Data analysis

The data collected in the present study were statistically processed using PASW ver. 18.0 (SPSS Inc., Chicago, IL, USA). The intergroup normality was tested, and the data did not satisfy the required normality. Therefore, non-parametric tests were conducted. Intergroup homogeneity was verified through chi-squared tests and the Mann-Whitney U test. Wilcoxon's signed-rank tests were conducted to compare the pre- and post-intervention values, and the Mann-Whitney U test was conducted to compare differences in the pre- and post-intervention values of the experiment group and the control group. The significance level was set to $p<.05$.

Results

Comparison of the pre- and post-intervention values of the experimental and control groups

According to the pre- and post-intervention values of the gait ability (Table 2), balance ability (Table 3), and pulmonary function (Table 4) in the UTGT group versus those in the OTGT group, all the resultant values significantly improved ($p<.05$), except the FEV1 ($p>.05$) in the OTGT group. According to the between-group comparisons, the improvements were significantly greater in the UTGT group ($p<.05$), except in the 10 MWT ($p>.05$).

Discussion

In the our study, the gait ability, balance ability, and pulmonary functions of both the UTGT and OTGT groups improved, but the balance ability and pulmonary functions were better in the UTGT group. The gait ability was the same in both groups. The results of the gait ability, balance ability, and pulmonary functions of the two groups revealed that the UTGT was more effective than that of the OTGT with respect to improvements in balance ability and pulmonary functions but not in gait ability.

In the our study, although UTGT was more effective than OTGT in improving balance ability, but its effects on gait ability were insignificant. The effects of UTGT and OTGT on stroke patients, the gait and balance ability were significantly more improved in the UTGT group (Kim et al, 2011). Park et al (2014) reported that gait training in stroke patients using UTGT increased the gait and balance ability. In other studies of stroke patients, UTGT increased balance ability with the weight shift to the paretic side, so that overall the weight shifts of the feet and heels increased (Park et al, 2010). In a study of

Table 2. Comparison of gait ability outcomes within groups and between groups

10 MWT[c] (s)	UTGT[a]	OTGT[b]	p
Pre-test	24.49±8.79[d]	20.64±6.27	.24
Post-test	20.64±6.27	17.04±5.43	.31
p	.01*	.01*	
Change value (post-pre)	−3.93±1.92	−3.60±1.84	.52

[a]underwater treadmill gait training, [b]overground treadmill gait training, [c]10 m walk test, [d]mean±standard deviation, *p<.05.

Table 3. Comparison of balance ability outcomes within groups and between groups

		UTGT[a]	OTGT[b]	p
TUG[c] (sec)	Pre-test	31.32±15.94[d]	22.88±7.79	.28
	Post-test	25.65±15.43	19.89±8.35	.63
	p	.01*	.01*	
	Change value (post-pre)	−5.11±2.57	−2.52±1.24	.01*
BBS[e] (score)	Pre-test	36.20±5.83	37.60±5.78	.35
	Post-test	43.50±5.13	41.80±4.73	.28
	p	.01*	.01*	
	Change value (post-pre)	7.30±1.64	4.20±1.87	.01*
Center of pressure (cm)	Pre-test	3.65±1.11	3.57±.71	.74
	Post-test	4.54±.97	4.09±.62	.28
	p	.01*	.01*	
	Change value (post-pre)	.91±.38	.44±.15	.01*

[a]underwater treadmill gait training, [b]overground treadmill gait training, [c]timed up and go, [d]mean±standard deviation, [e]Berg balance scale, *$p<.05$.

Table 4. Comparison of pulmonary function outcomes within groups and between groups

		UTGT[a]	OTGT[b]	p
FVC[c] (L)	Pre-test	1.52±.62[d]	2.08±1.03	.17
	Post-test	1.94±.65	2.24±.97	.27
	p	.01*	.01*	
	Change value (post-pre)	.42±.06	.16±.17	.01*
FEV1[e] (L)	Pre-test	1.31±.51	1.81±.88	.15
	Post-test	1.77±.55	2.02±.87	.21
	p	.01*	.44	
	Change value (post-pre)	.45±.06	.16±.17	.01*
FEV1/FVC (%)	Pre-test	86.37±3.34	87.09±2.09	.30
	Post-test	91.39±3.36	90.43±2.03	.33
	p	.01*	.01*	
	Change value (post-pre)	5.01±1.80	3.33±1.16	.04*

[a]underwater treadmill gait training, [b]overground treadmill gait training, [c]forced vital capacity, [d]mean±standard deviation, [e]forced expiratory volume at one second, *$p<.05$.

UTGT by Jung et al (2010) that applied additional weight to the paretic side of stroke patients with reduced circumduction gaits due to hip joint abduction, adding weight to the paretic side during gait training improved balance ability. UTGT against water flow increased gait and balance ability then OTGT in elderly women (Shono et al, 2007). In recent study, UTGT in adults with osteoarthritis was more effective than OTGT for reducing joint pain, improving balance and mobility (Bressel et al, 2014). We thought that buoyancy, hydrostatic pressure, and viscosity of water affect the balance ability of stroke patients such as supporting the body sway and the weight bearing.

In the our study, the pulmonary function of the UTGT group was better than that of the OTGT group. Chu et al (2004) reported that underwater exercise was effective in improving the breathing/ventilation abilities, heart rates, and maximum oxygen uptake of stroke patients. In a comparison of UTGT and OTGT gait training performed by elderly people, those who performed the UTGT had higher activity of the lower extremity muscles, higher cardiopulmonary responses, and higher RPE scores (Masumoto et al, 2008). In a study of the effects of UTGT at different water depths on stroke patients' physical responses, gait, and trunk muscle activity, UTGT at all water depths significantly increased heart rates and trunk muscle activity compared to OTGT at all speeds (Sin, 2012). UTGT may affect to increase the strength of respiratory muscles, improves trunk muscle activity, and exerts physiological effects on cardiopulomonary endurance, cardiovascular responses, and breathing ability with the characteristics of water.

Most previous stroke studies of UTGT and OTGT focused on speed, and they were conducted for short periods as one-off studies, with small numbers of subjects. More studies on underwater exercise by stroke patients are needed that include psychological/physiological elements, such as different water depths. Studies of the impacts of UTGT training exercise on the pulmonary function of stroke patients are also needed. In the our study, we compared the RPE scores of stroke patients who participated in UTGT and OTGT. According to previous studies, UTGT resulted in higher RPE scores, higher activity of the lower extremity muscles, and higher trunk muscle activity than OTGT. However, the stroke patients who participated in the present study indicated that the UTGT was easier than the OTGT. Thus, it appears that psychology plays a role and may act as a constraint during gait training.

These results suggest that underwater exercise programs should be included in the rehabilitation treatment of stroke patients and that these underwater exercise programs should include UTGT. UTGT can improve stroke patients' functional mobility and independent gait ability and shorten the time necessary for a return to daily living. As the study group consisted of only 20 patients and was limited to stroke patients of a specific height range to ensure the same water depth in the UTGT, the results cannot be generalized. he subjects of the present study was limited to 20 patients, and many diverse subjects could not be included. We suggest to future study with greater numbers of patients that include more physiological and psychological factors are needed to determine the impact of UTGT on stroke patients.

Conclusion

The current study findings provide clinical evidence that UTGT is more effective to improve the gait, balance and pulmonary ability in stroke patients. The subjects were underwent UTGT and OTGT for 30 min per time, 3 times per week, for 4 weeks. The results show that UTGT results in improved balance ability and pulmonary functions then OTGT. We can conclude that UTGT is more effective than OTGT in improving balance ability and pulmonary functions. Based on the findings of the present study, various physical characteristics of water such as buoyancy, hydrostatic pressure, and viscosity may provide resist to respiratory muscles, stability to body sway and efficient exercise with reducing fear of falling in the stroke patients. Our results suggest that UTGT should included in be the exercise programs of stroke patients. We can also conclude that UTGT can help to improve the pulmonary functions of stroke patients.

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