Original Article

J. Phys. Ther. Sci.
27: 3549–3553, 2015

The effects of aquatic trunk exercise on gait and muscle activity in stroke patients: a randomized controlled pilot study

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Abstract. [Purpose] The purpose of this study was to investigate the relationship between muscle activity and gait function following aquatic trunk exercise in hemiplegic stroke patients. [Subjects and Methods] This study's participants included thirteen hemiplegic patients (ten males and three females). The aquatic therapy consisted of administering concentrative aquatic therapy for four weeks in a therapeutic pool. Gait parameters were measured using a gait analysis system adjusted to each subject's comfortable walking speed. Electromyographic signals were measured for the rectus abdominis, external abdominal oblique, transversus abdominis/internal-abdominal oblique, and erector spine of each patients. [Results] The pre- and post-training performances of the transversus abdominis/internal-abdominal oblique were compared statistically. There was no statistical difference between the patients' pre- and post-training values of maximal voluntary isometric contraction of the rectus abdominis, but the external abdominal oblique values tended to improve. Furthermore, gait factors improved significantly in terms of walking speeds, walking cycles, affected-side stance phases, affected-stride lengths, and stance-phase symmetry indices, respectively. [Conclusion] These results suggest that the trunk exercise during aquatic therapy may in part contribute to clinically relevant improvements in muscle activities and gait parameters.
Key words: Aquatic trunk exercise, Gait, Muscle activity

(This article was submitted Jul. 22, 2015, and was accepted Aug. 19, 2015)

INTRODUCTION

Aquatic therapy has been suggested as an effective approach for improving trunk activity in stroke patients[1–4]. Typically, stoke patients suffer from deficits in their functional ambulation capacities, balance, walking velocities, cadences, stride lengths, and temporal-gait and muscular-activity patterns[5–8]. An understanding of the physical properties of water and the physiology of human immersion, coupled with the skills necessary to analyze human movement, have helped physiotherapists use hydrotherapy as a tool for facilitating movement and restoring functionality[9]. Because of its wide margin of therapeutic safety and clinical adaptability, aquatic therapy has also proved very useful in clinical settings for rehabilitating patients with musculoskeletal problems, neurologic problems, cardiopulmonary pathologies, and other conditions[10]. Among the suggested aquatic exercise techniques, the Halliwick method uses

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Table 1. Interventional program of aquatic exercise during the four weeks

Warming up (5 min) Trunk control session	Halliwick Ten Point Program Sagittal rotation control Transversal rotation control Longitudinal rotation control Combined rotation control
Treatment (20 min) Trunk-specific exercise session	1. Abdominal hollowing 2. Abdominal bracing 3. Anteroposterior (AP) pelvic tilts 4. Mediolateral (ML) pelvic tilts
Cool down (5 min) Trunk control session	Halliwick Ten Point Program Sagittal rotation control Transversal rotation control Longitudinal rotation control Combined rotation control WATSU

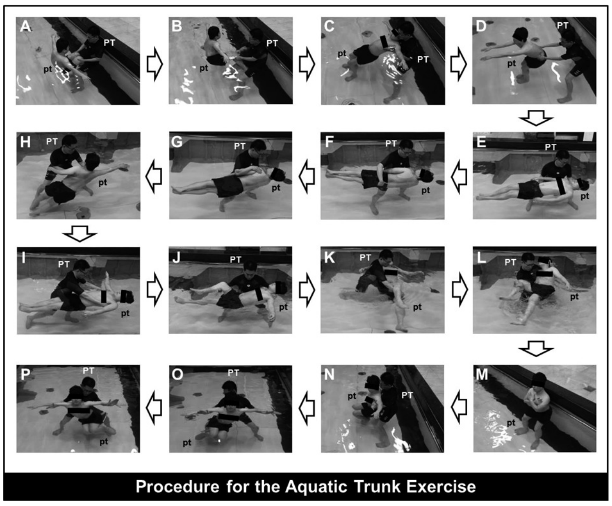

Fig. 1. Photographic representation of the procedure for the aquatic trunk exercise in hemiplegic stroke patients
Gait parameters and muscle activities were measured using a gait analysis system and electromyogram, as described in the Subjects and Methods section. A, start of aquatic trunk exercise; P, end of aquatic trunk exercise; PT: physical therapist; pt: stroke patient

fluid mechanics to help patients most achieve stability and controlled movement in water[1, 11]. The Ten Point Program is a structured learning process that facilitates the practical application of the Halliwick concept, and its elements are taught and learned logically and gradually through games and activities. WATSU (Water Shiatsu), another water therapy, has also been widely applied in various therapeutic settings, including treatment for chronic conditions with disabilities like back pain, neuromuscular activity, cerebral palsy, osteoarthritis, rheumatoid arthritis, cardiovascular fitness, and stroke[2, 3, 9, 12–16]. WATSU is a complementary therapeutic treatment comprising passive stretch and massage techniques administered in appropriately warm water[17]. Recent studies on trunk exercise in water have assessed the surface EMG activity of the rectus abdominals, external obliques, lower abdominals, multifidus, and erector spine during aquatic therapy[12, 13]. However, studies on the relationship between trunk-muscle activity and gait parameters after therapeutic aquatic exercises aimed at treating stroke patients are rare. Therefore, the purpose of the present study was to investigate the relationship between trunk-muscle activity and gait parameters following aquatic trunk exercise in stroke patients.

SUBJECTS AND METHODS

The participants in this study included thirteen hemiplegic patients (ten males and three females) who had received stroke diagnoses and were receiving admission or outpatient treatment at P rehabilitation center. The inclusion criteria for subject selection were as follows: the patient had to (1) have a history of only one cerebrovascular accident, (2) exhibit an independent gait (without the assistance of a device), (3) have a stable of cardiovascular status, (4) be experiencing no significant musculoskeletal problems (fracture, back pain, etc.), and (5) have a Korean mini-mental state examination (K-MMSE) score > 24 points. The aquatic therapy consisted of administering concentrative aquatic therapy for four weeks (30 min per session, three days per week) in a therapeutic pool with a water depth equal to the xiphoid process (115–120 cm) and a water temperature of 30 °C (air temperature=24 °C)[1, 8]. The aquatic-therapy regimen was based on Halliwick, WATSU, and trunk-specific exercise methods, and its purpose was to improve the activation of trunk muscles associated with gait parameters in stroke patients. Aquatic exercise sessions consisted of a warm-up, trunk-specific exercises, and then a cool-down period (Table 1)[18–20]. The basic exercises in the Halliwick method for balance restoration concentrate on sagittal rotation control (bending from left to right or transferring weight while in an upright position), longitudinal rotation control (the ability to control movement around the sagittal-frontal axis whether in the vertical position or floating horizontally, e.g., to rotate in the same place while standing or to do so while supine and floating prone with one's face in the water), transversal rotation control (around the transverse axis with the subject moving from standing to supine and then returning to the standing position), and combined rotation control (a combination of transverse sagittal and longitudinal rotations) (Fig. 1)[21]. WATSU is a body-based method comprising buoyancy, passive stretching, and massage techniques, including massage and palpation of acupuncture points administered in warm water[3]. All participants received conventional multidisciplinary physical and occupational therapy, as provided by the rehabilitation staff, and they were mainly focused on neurodevelopmental treatments. Gait parameters were measured using a gait analysis system (Gait Trainer 2 analysis system, Biodex Medical Systems Inc., Shirley, NY, USA) adjusted to each subject's comfortable walking speed. This equipment can analyze various walking parameters, such as walking speed, walking cycle, affected-side stance phase, affected-side stride length, stance-phase symmetry index, and stride-length symmetry index, using a sensor installed on the treadmill floor. Outcomes were measured

Table 2. Clinical characteristics of the hemiplegic stroke patients

Variable	Stroke patients
Age (yr)	50.5 ± 2.9
Gender	
Male (%)	10 (76.9)
Female (%)	3 (23.1)
Height (cm)	166.4 ± 1.9
Weight (kg)	66.6 ± 2.9
BMI (kg/m²)	24.0 ± 0.8
Cause of stroke	
Infarction (%)	10 (76.9)
Hemorrhage (%)	3 (23.1)
Affected side	
Right (%)	10 (76.9)
Left (%)	3 (23.1)
Onset (mo)	24.1 ± 3.8
K-MMSE (score)	24.9 ± 0.4

All data are presented as the mean±SE. BMI: body mass index; K-MMSE: Korean version of the Mini-Mental State examination

Table 3. Changes of muscle activity of the paretic side using EMG after the four-week intervention

Variable	Before treatment	After treatment
RA (%MVIC)	56.0 ± 1.8	56.2 ± 1.7
EO (%MVIC)	51.6 ± 1.6	55.1 ± 1.7
TrA/IO (%MVIC)	51.1 ± 1.8	56.2 ± 1.9*
ES (%RVC)	58.3 ± 1.8	57.0 ± 1.5

All data are presented as the mean±SE. RA: rectus abdominis; EO: external abdominal oblique, TrA/IO: transversus abdominis/internal-abdominal oblique; ES: erector spine; MVIC: maximal voluntary isometric contraction; RVC: reference voluntary contraction. *$p < 0.05$

twice, once before training and once after four weeks of training. Furthermore, EMG data were collected using a BTS FREEEMG 1000 (BTS S.p.A., Via della Croce Rossa, Italy) with surface electrodes and the sampling rate set at 1,000 Hz per channel; the EMG signals were band-pass filtered from 20 to 500 Hz[12, 13]. Pre-gelled, bipolar silver/silver-chloride surface electrodes (3M, Maplewood, MN, USA) were placed with an interelectrode distance of 20 mm. EMG signals were recorded for the rectus abdominis (RA), external abdominal oblique (EO), transversus abdominis/internal-abdominal oblique (TrA/IO), and erector spine (ES) of each patient's paretic side. The electrode attachment regions were as follows: (1) for the RA, 5 cm above the umbilicus and 3 cm lateral from the midline; (2) for the EO, approximately 15 cm lateral to the umbilicus; (3) for the IO, 2 cm inter-medial to the anterior superior iliac spine (ASIS); (4) for the ES, 3 cm lateral to the spine (L4–5 spinous process). Each electrode was attached by a qualified physiotherapist to regions identified using anatomical landmarks, which had previously been shaved and cleaned using alcoholic wipes. The EMG values for the RA and IO muscles were measured during maximal voluntary isometric contraction (MVIC). EMG values for the ES were measured during reference voluntary contraction (RVC) because of how strokes can make MVIC movement difficult. The obtained EMG values were normalized (%MVIC, %RVC) for comparison with the mean. Each muscle's performance was measured by MVIC/RVC three times to determine an average value. The contraction time was 5 seconds, and normalized values were recorded for the middle three-second MVIC values[12, 13]. While recording these measurements, the examiner verbally encouraged the subjects to put forth the maximum effort possible. Statistical analyses were conducted using the PASW Statistics software (version 18.0) to calculate averages and standard deviations. The data were expressed as the mean ± standard error (SE). The significance level was set to $\alpha=0.05$ when performing the paired t-test. The study's protocol was approved by the Committee of Ethics in Research at the University of Yongin, in accordance with the terms of Resolution 5-1-20. Furthermore, all volunteers provided informed consent prior to participating in the study.

RESULTS

The clinical and general characteristics of the 13 participants are listed in Table 2. Their pre- and post-training %MVIC values for the TrA/IO were compared statistically (pre, 51.1 ± 1.8; post, 56.2 ± 1.9; p=0.041). There was no statistically significant difference between pre-training and post-training %MVIC values for the RA, but those for the EO tended to improve (pre, 55.6 ± 2.0, and post, 55.9 ± 1.9 for the RA; pre, 51.8 ± 1.9, and post, 54.6 ± 1.9, for the EO) (Table 3). There was also no statistically significant improvement in the %RVC values for the ES after four weeks; indeed, they tended to worsen (pre, 58.3 ± 1.8; post, 57.0 ± 1.5; p=0.485) (Table 3). However, almost every gait factor was significantly improved, including walking speeds (pre, 51.4 ± 5.1; post, 57.9 ± 7.0; p=0.020), walking cycles (pre, 0.45 ± 0.03; post, 0.41 ± 0.04; p=0.011), affected-side stance phases (pre, 36.2 ± 4.2; post, 46.5 ± 3.0; p=0.004), affected-stride lengths (pre, 60.2 ± 4.5; post, 67.7 ± 5.4; p=0.009), and stance-phase symmetry indices (pre, 62.6 ± 12.4; post, 84.2 ± 9.0; p=0.41) (Table 4). Although not significant, there was also improvement in the patients' stride-length symmetry indices (pre, 92.9 ± 5.5; post, 100.0 ± 5.7; p=0.545) (Table 4).

DISCUSSION

The present study demonstrates that four weeks of aquatic exercise using a program based on the Halliwick and WATSU methodologies, as well as trunk-specific exercises, improves some muscle activity and gait parameters. Regarding the collected EMG values for the subjects' trunk muscles, there were no significant differences, but the subjects' gait parameters did improve, despite the relatively short duration of this study. According to previous studies on trunk-muscle activity in water and on land, trunk muscle activation is lower in water than on land when subjects perform the same trunk exercises. Nevertheless, the pres-

Table 4. Changes of gait parameters after the four-week intervention

Variable	Before treatment	After treatment
Walking speed (cm/sec)	51.4 ± 5.1	57.9 ± 7.0*
Walking cycle (cycle/sec)	0.35 ± 0.03	0.41 ± 0.04*
Affected-side stance phase (sec/%)	36.2 ± 4.2	46.5 ± 3.0**
Affected-side stride length (cm)	60.2 ± 4.5	67.7 ± 5.4**
Symmetry index of stance phase (%)	62.6 ± 12.4	84.2 ± 9.0*
Symmetry index of stride length (%)	92.9 ± 5.5	97.0 ± 5.7

All data are presented as the mean±SE. *$p < 0.05$; **$p < 0.01$

ent study shows that trunk exercises in the water enhance EMG values in trunk muscle, especially the TrA/IO muscles, which are activated during trunk rotation. Additionally, TrA/IO muscles experience greater activation than other trunk muscles during abdominal hollowing and bracing. Thus, it is thought that activation of the TrA/IO would improve trunk functionality more than other trunk exercises from the Halliwick and trunk-specific portions of this study's experimental regimen[22, 23]. Meanwhile, the results of the present study showed that the EMG values for the patients' ES muscles tended to decrease at the end of the treatment period. EMG values for the patients' ES muscles were measured as the %RVC in the present study because of movement difficulties MVIC measurements would have entailed. In previous studies on the trunk muscle activity of stroke patients, paretic-side ES muscles were shown to undergo greater activation than their non-paretic counterparts during their work and rest phases. The reasons for higher EMG ES values in stroke patients were likely augmented by an increase in their use of motor units to compensate for stroke-induced decreases in discharge rate during motor unit firing[24]. Also, explanations for these differences might depend on the extent to which cortical influences on muscles are disrupted by a stroke[24]. Therefore, these results indicate that the subjects' trunk stability improved over the course of the study's experimental aquatic therapy. Previous studies have also found that trunk flexion and extension muscle weakness were correlated with the Berg Balance Scale score and locomotion and transfer items in the Functional Independence Measure[25]. Moreover, Verheyden et al. reported that trunk performance remains impaired after a stroke and that the strong correlation between this and measurements of balance, gait, and functional abilities confirm the importance of trunk rehabilitation[26]. However, studies about the effectiveness of aquatic therapy in improving trunk activity and gait parameters in stroke patients have rarely been performed. Similar research suggests that postural balance and knee flexor strength were improved after aquatic therapy based on the Halliwick and Ai Chi methods in stroke survivors, and such studies have also reported that there is no significant change in gait. Likewise, one study evaluated gait improvement using to Modified Motor Assessment Scale gait score (range 0–6), but this tool is insufficient for analyzing gait parameters in stroke patients[1]. The present study utilized a Gait Trainer 2 and GAITRite system to analyze gait parameters with a sensor installed on the treadmill's floor. This method has been used in many studies to provide adequate assessments of hemiplegic gait parameters, and the present results coincide with those of previous studies that have used Gait Trainer systems to evaluate gait parameters in stroke patients[27]. Perry suggests that hemiplegic patients have short stride lengths and slow gait velocities[28]. Mumma attests that the greatest loss after a stroke is gait ability and that hemiplegic patients exhibit slow gait velocities and unaffected lower-extremity compensation movements[29]. Some studies have not only emphasized the nature of the relationships between gait speed and other temporal and spatial gait parameters but also associated them with walking speed and symmetry in patients with stroke-induced hemiplegia[30, 31]. According to the present data, subjects' walking speeds and cycles improved significantly, as did their affected-side stance phases, affected-stride lengths, and stride-length symmetry indices. Thus, the present results demonstrate that aquatic therapy as part of a supervised program greatly benefits gait parameters in stroke patients. This is clearly due to how the water environment acts as a partial support for the body, allowing for mobilization of joints. Also, aquatic therapy provides motor and sensory stimuli that can potentially improve balance and muscle function[4, 32]. The popularity of aquatic physical therapy has increased recently among neurological-rehabilitation physical therapists and researchers because of the many benefits such therapy provides. Furthermore, the buoyancy of water might allow stroke patients to move with less effort and across movement planes that would be impossible on land without assistance[33]. Thus, one may conclude that aquatic therapy is a beneficial therapeutic method for gait training in stroke patients who experience trunk control difficulties. In summary, trunk exercise combined with aquatic therapy achieves clinically relevant improvements in TrA/IO activation and gait parameters. However, to design and carefully implement a long-term intervention for stroke patients, more multidimensional and scientific investigations are needed[34–36].

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