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Efficacy of aquatic exercise on pulmonary function and aquatic skills performance in older children with cerebral palsy. Randomized controlled study

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Abstract

Introduction. To evaluate the effectiveness of the aquatic aerobic exercise training (AqET) on the pulmonary function (PF) and aquatic skills performance in the older children with spastic cerebral palsy (CP). Randomized controlled study.

Methods. Twenty-eight children, 13–15 years old, with spastic CP were randomly allocated into AqET group (n = 13; received AqET plus traditional Physiotherapy "TPT" program) and control group (n = 15; received TPT only). The PF [including (the forced vital capacity; FVC), (forced expiratory volume in one second; FEV1)] and the aquatic skills performance (including the WOTA mental adaptation score "WMA", the WOTA skills balance control movement score "WSBM", the WOTA total score "WTOT") were evaluated at the beginning and after 12-weeks.

Results. Post-study results revealed significant increases in the PF, WMA, WSBM, WTOT mean values in both groups. The FEV1% and FVC% mean values and percentages of changes were [84.00% (21.5%), 78.23% (24.56%)] and [(71.13% (6.9%), 62% (7.12%)] for the AqET, and control groups respectively. The WMA, WSBM, WTOT mean scores and percentages of changes were [33.15 (77.01%), 15.46 (643.27%), 48.62, (133.19%)] and [(20.2 (7.59%), 2.27 (23.89%), 22.47 (7.36%) for the AqET, and control groups respectively ($p < 0.05$). There were significant differences between-groups in the PF and the aquatic skills performance post-study, but in favor of AqET group.

Conclusions. Children with spastic CP benefit favorably from AqET or TPT programs. The AqET is more beneficial than the TPT in increasing the PF and the aquatic skills performance in older children with spastic CP.

Key words: hydrotherapy, exercise, lung volume measurements, children, cerebral palsy

Introduction

Cerebral Palsy (CP) is a group of disorders caused by a non-progressive immature brain damage, resulting in variable degrees of physical disabilities among children [1]. Physiological classification of the CP is based on the site of the brain lesion causing the motor disorder and is categorized into either pyramidal (spastic type; accounts for about 70–80% of all CP cases) or extra-pyramidal (nonspastic type; accounts for about 30% of all CP cases) [2, 3]. Another topographic classification considered the predominant motor disturbances and the pattern of limbs involvement; categorized the cerebral palsy into many patterns including monoplegia (involvement of one limb), diplegia (involvement of both upper limbs), triplegia (involvement of three limbs), hemiplegia (involvement of both upper and lower limbs of the same side) or quadriplegia (involvement of the four limbs) [3]. Hemiplegia and diplegia are the most commonly encountered CP types according to motor impairment's topographic distribution [4]. Retarded motor activation and physical inactivity are major contributors to the abnormally reduced functional performance and aerobic capacity commonly encountered in children with CP compared to counter-partner healthy children [5].

The CP-induced skeletal muscles weakness or paralysis, decreased activity level, delayed cardiopulmonary system development, and retarded physical activities are all associated with respiratory dysfunction and reduced functional capacity [6, 7]. Pulmonary complications are among the primary causes for hospitalization [8] as well as deteriorated quality of life in severe CP cases [9].

The respiratory disorders are the commonest cause of morbidity and mortality [10], with the respiratory failure is recognized as the primary cause of death among patients with CP [11]. Patients with CP are at increased risk for recurrent chest infection, pneumonia, atelectasis and chronic respiratory failure [12]. Patients with spastic CP are usually encountered with reduced chest wall mobility, chest shape abnormalities, and weak respiratory muscles that predispose them to abnormally reduced pulmonary functions (PF) compared to their normal counter partners [13]. Either obstructive or restrictive PF abnormalities are commonly seen in patients with CP [14].

Aquatic exercise training (AqET) is one of the most useful approaches in the treatment of children with CP [15] The ease of the aquatic exercise performance allows the children with CP to perform body movements that are difficult on the ground and hence; augmenting many physiological and psychological parameters [15, 16].

Varieties of AqET approaches have been described [17–19]**,** with the task-based techniques are more preferable because it facilitates movements, enhances sensory inputs, encourages active participation of the child [17, 18] and improves physical performance and vital capacity in children with CP [15]. Although the beneficial physical and physiological effects of the AqET in children with CP; more research is still warranted in this area [20] and randomized-controlled studies comparing the effects of adding an AqET to the traditional care program of children with CP are needed [21]. The objective of this study was to evaluate the effects of the AqET on the PF and aquatic task performance in old children with CP.

Subjects and methods

Research design

This study followed the randomized controlled study design, adhered to the principles of the Declaration of Helsinki 1975, revised in 2000, and was approved by the ethics committee of the General Organization for Teaching Hospitals and Institutes (approval number INM00032). Initially; parents signed an informed consent for voluntarily participation, enrolment and agreeing for publication the study results. This study took place from May 2020 to September 2021.

Subjects

Thirty-Seven children diagnosed with spastic CP were recruited from National Institute of Neuromotor System. Initially; nine patients were excluded because of variety of reasons including distance and transportation barriers (n = 2), not interested (n = 4), recent use of bronchodilators (n = 3). After baseline screening; The Twenty-Eight (11 male, 17 female) eligible children with spastic CP were randomly allocated via simple random sampling technique (Probability sampling) using an online random numbers generator program (http://www.randomization.com) into one of the two groups; the Aquatic aerobic exercise training group (AqETG; *n* = 13) and control group (CG; *n* = 15) (Figure 1).

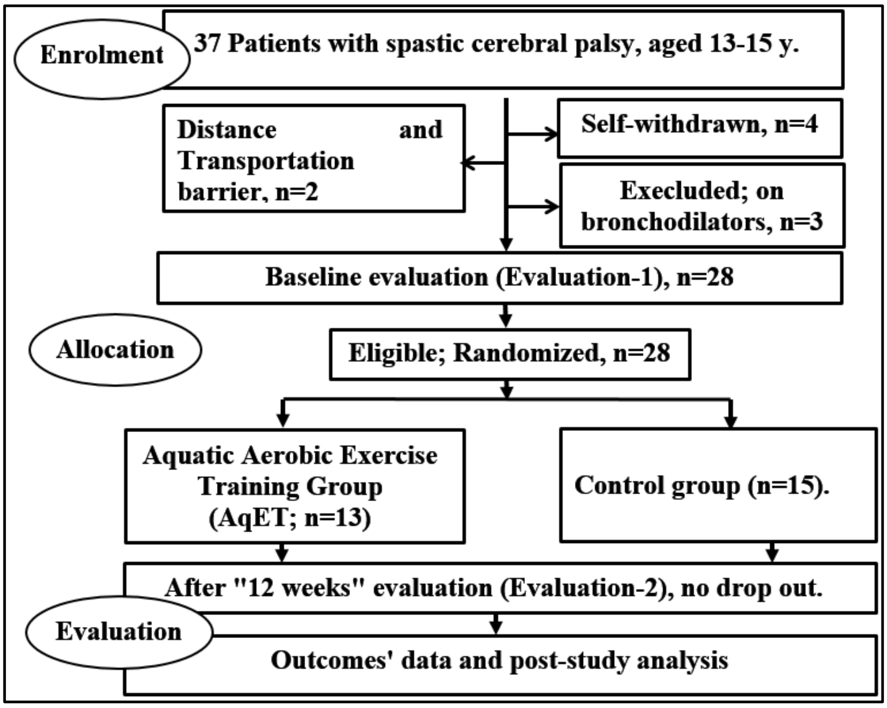


Figure 1. Patients' flowchart

Inclusion criteria

Children diagnosed with spastic CP (diplegia and hemiplegia), aged 13–15 years old, able to follow instructions, able to walk with or without assistive ambulatory aid, with Gross Motor Function Classification System (GMFCS) scores I and II (Participant was able to walk with or without hand-held mobility devices, but with limited jumping and running speed, limited balance and coordination and experienced difficulty walking long distances, have not been previously included in any form of regular AqET, able to follow instructions, were all included in this study.

Exclusion criteria

Children with neurological/ psychiatric disorders other than the CP, had a recent history of botulinum toxin injection within the last three months, had orthopedic surgery within the last six months, with GMFCS score of four or five, children with open wounds, with acute cardiorespiratory or other systemic disorders, receiving medications that affect the performance and accuracy of evaluations' results (e.g., bronchodilators) were all excluded at the beginning of study.

Study procedures

After parental approval, all children underwent the same medical screening and evaluation protocols including initially a full history taking and physical assessment, followed by assessment of the child's ventilatory functions (VF) and aquatic skills performance. All participants/ parents were informed they were free to withdraw at any time throughout the study. A preliminary power analysis was conducted to determine proper sample size using an online G-Power program with (1-β error probability) = 0.95, alpha error probability = 0.05, effect size = 0.7, number of groups = 2; determining a sample size of 28 participant to produce reliable results.

Outcome measures

The main outcome variables were the VF (including the forced vital capacity "FVC", forced expiratory volume in one second "FEV1", FEV1/FVC, peak expiratory flow "PEF") and the aquatic skills performance (evaluated by the Water Orientation Test Alyn 2 (WOTA 2). The variables were evaluated pre-study (evaluation-1) and after twelve weeks (evaluation-2, preceded by two non-training days to avoid the interference of the "acute post-exercise effects" on the study results. All tests were standardized for all participants and each therapeutic intervention was conducted by an experienced therapist. A preliminary educational session was conducted to ensure participants' well-recognition of the evaluation procedures and treatment protocols. The utilized instruments were periodically checked and calibrated according to the manufactured guidelines.

Demographic participants' characteristics

Collection of basic characteristics of all participants ran according to the standard procedures. While wearing light comfortable clothes; weight in kg, height in meter were evaluated using a portable stadiometer (ProMed® 6129, USA) while the child was standing erect. BMI in kg/m^2 (weight/height^2) was also calculated. Each participant's GMFCS score was evaluated to determine the present gross motor function according to previously described guidelines [22].

The ventilatory functions assessment

To ensure reliability of the assessment procedure, the VF of all children with CP were evaluated by the same therapist using portable computerized PF testing unit (Spiro Analyzer ST 250, Japan). After 10-minutes rest; the VF were evaluated for each child following previously described protocol [23]. Clear instructions were simplified and explained step-by step for each child. After three normal breaths; each child was encouraged to inspire then expire air most deeply and rapidly through the mouthpiece while the nose clips were put on. Each child was continuously directed to tightly hold the disposable mouthpiece with his lips to prevent air leakage. The maneuver was repeated three times with sufficient rest time in between; the best readings of the FVC, FEV1, FEV1/FVC and PEF were then recorded.

Aquatic skills performance assessment

Water Orientation Test Alyn 2 (WOTA 2) is a valid and reliable test [24], used to assess the child level of mental adjustment and function in water (balance control and movement). The WOTA 2 is a several-skills test and is based on the principles of Halliwick concept's 10-point program. Therapist simply explained the required task verbally and demonstrated it to the child who was then encouraged to perform each task three times. Therapist scored the child's performance on a 4-points scale, the "0" score indicated that the child did not perform the task or did not cooperate in spite of his ability to do it, the "3" score indicated independent performance of the task with or without therapist's supervision. If conflict existed between two scores; the lower score was chosen. The Wota mental adaptation (WMA) score, the Wota skills balance control movement (WSBM) score and the Wota total score (WTOT) score were calculated according to previously described procedure [25].

Interventions

Both interventions were designed to maximize participants' enjoyment and benefits to minimize the child's drop-out.

Aquatic aerobic exercises training (AqET)

Thirteen children received the moderate intensity AqET program following previously established protocol [26], in addition to the TPT recently described by Atia and Tharwat [27].

Participants in the AqETG received 60-minutes AqET session, 3-times/ week, for 12-successive weeks in the swimming pool (70–180 cm depth, 4 × 6 m area). Each AqET session was performed with a one-to-one therapist-patient ratio, preceded, and ended by 10-minutes warm-up and cool-down (at 50%–60% training intensity) and composed of 40-minutes AqET (at 70%–80% training intensity), with a 27.7°C water temperature. The AqET intensity was checked each 10-minutes from participant's index figure, using the pulse oximeter (CMS50DL, China).

The warm-up and cool-down phases were composed of light intensity in-water exercises (slow walking and stretching exercises for large muscles' groups). The AqET included 5-minutes of each of the following tasks: walking, shuttle running, jumping, deep water running, creeping, kicking, swimming, ball and chasing games.

The AqET intensity was adjusted according to the aquatic target heart rate (THR) training formula, [28] using the resting heart rate (RHR) where:

$$\text{THR zone} = 50\% \text{ to } 80\% \, [(200 - \text{age}) - \text{RHR}] + (\text{RHR}) - 17$$

Control group (CG; *n* = 15)

Fifteen children received only the TPT previously described by Atia and Tharwat [27] and included neurodevelopmental techniques, stretching exercises for major muscles' groups, postural correction exercises, gait training exercises, balance and breathing exercises.

Statistical analysis

The SPSS version 20 (SPSS Inc, Chicago, IL) was used for statistical analysis. Normal data distribution was checked by the Kolmogorov–Smirnov test. Continuous data was presented as mean ± *SD*, while categorical data was expressed as frequency and percentages. The VF and the aquatic skills' related assumptions were evaluated within-groups using the paired *t*-test and between-groups using the one-way ANOVA, the Bonferroni testing was used for the post-hoc analysis. *P*-value < 0.05 was accepted as statistically significant.

Ethical approval

The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the General Organization for Teaching Hospitals and Institutes (approval number INM00032).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The VF and the aquatic skills performance were evaluated pre- and post-study. Initially; there were non-significant statistical differences between-groups in the evaluated variables and the child's demographic characteristics ($p > 0.05$) (Table 1).

Table 1. The demographic characteristics of participants in all groups (mean ± *SD*)

Variables		AqETG (*n* = 13)	CG (*n* = 15)	*p*-value
Gender	male	8 (61.5%)	9 (60%)	0.96**
	female	5 (38.5%)	6 (40%)	
GMFCS	1	4 (30.8%)	2 (13.3%)	0.44**
	2	9 (69.2%)	13(86.7%)	
Age (year)		13.85±0.8	13.73±0.8	0.71**
Weight (kg)		48.39±4.13	46.8±5.36	0.4**
Height (m)		1.52±0.06	1.51±0.05	0.72**
BMI (kg/m^2)		20.98±1.01	20.53±2.05	0.48**

AqETG – Aquatic aerobic exercises training group, CG – control group, GMFCS – Gross Motor Function Classification System

level of significance at $p < 0.05$, ** non-significant

Demographic characteristics

There were non-significant differences in age (year; p = 0.71), body weight (kg; p = 0.4), height (m; p = 0.72), body mass index (kg/m^2; p = 0.48), GMFCS (p = 0.44), gender distribution (p = 0.96) between-groups at the beginning of the study (Table 1).

Within group's comparison

Post-study results revealed that there were significant increases in mean values of the FEV1 (p = 0.00) and FVC (p = 0.00), in AqETG group. Also, there were significant increases in mean values of the FEV1 (p = 0.00) and FVC (p = 0.00), in control group.

Post-study; the FEV1, FVC, FEV1/FVC mean values were (84.00%, 78.23%, 107.09%) and (71.13%, 62%, 108.97%), while the FEV1, FVC, FEV1/FVC percentages of changes were (21.5%, 24.56%, 2.84%) and (6.9%, 7.12%, 1.42%) for the AqET, and control groups respectively.

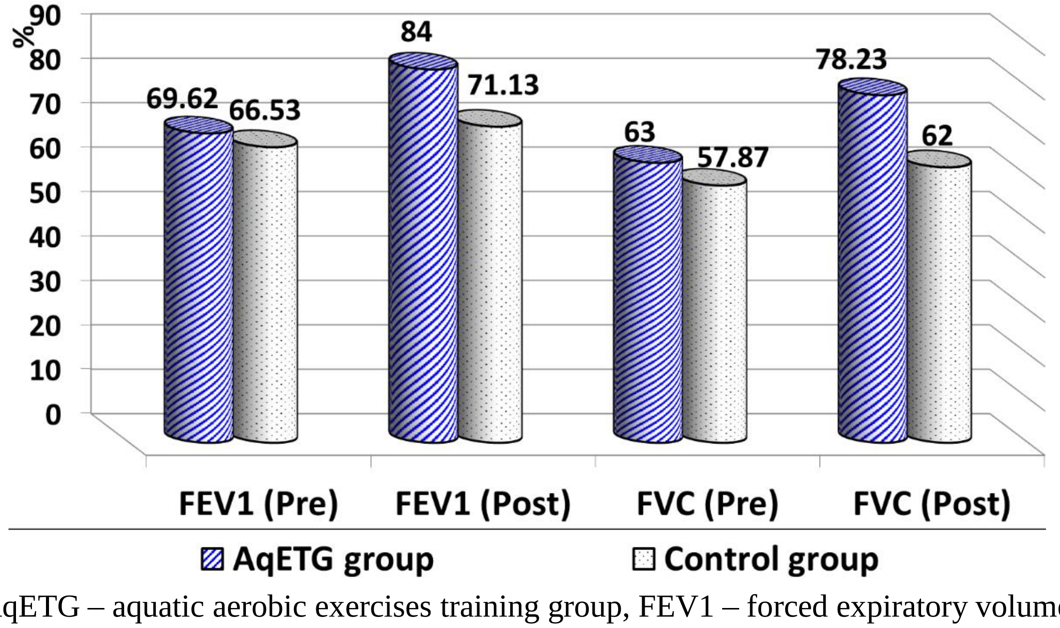
There were significant increases in mean values of the WMA (p = 0.00), WSBM (p = 0.00), WTOT (p = 0.00) mean scores in AqET group. There were significant increases in the WMA (p = 0.00), and WTOT (p = 0.0002), with non-significant increases of the WSBM (p = 0.55) in the control group.

Post-study; the WMA, WSBM, WTOT mean scores were (33.15, 15.46, 48.62) and (20.2, 2.27, 22.47), while the WMA, WSBM, WTOT percentages of changes were (77.01%, 643.27%, 133.19%) and (7.59%, 23.89%, 7.36%) for the AqET, and control groups respectively ($p < 0.05$).

Between-groups comparisons

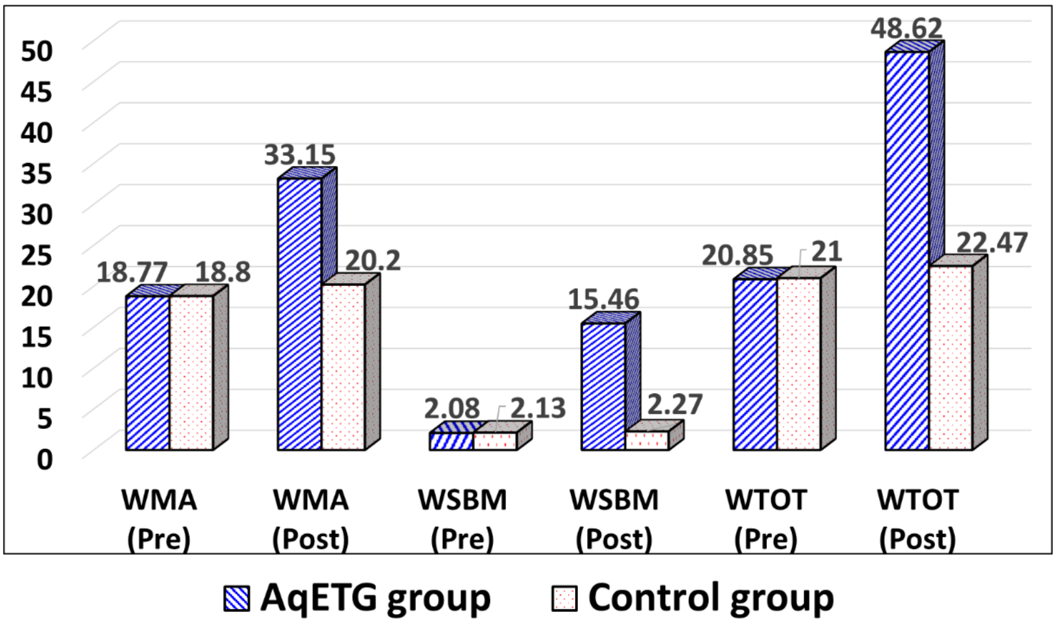
Pre-study results revealed that there were none-significant differences between-groups in the FVC% (p = 0.07) and FEV1% (p = 0.14). There were also non-significant differences between-groups in the WMA (p = 0.97), WSBM (p = 0.88), WTOT (0.86).

Post-study; there were significant differences in the ventilatory function and the aquatic skills performance mean values, but in favor of the AqET group ($p < 0.05$). There were significant differences in the FVC% (p = 0.00), FEV1% (p = 0.0001), WMA (p = 0.00), WSBM (p = 0.00), WTOT (p = 0.00) (Figure 2, 3).



AqETG – aquatic aerobic exercises training group, FEV1 – forced expiratory volume in one second, FVC – forced vital capacity

Figure 2. Between-groups comparison of the ventilatory function



AqETG – aquatic aerobic exercises training group, WMA – WOTA mental adaptation score, WSBM – WOTA skills balance control movement score, WTOT – WOTA total score

Figure 3. Between-groups comparison of the aquatic skills performance

Discussion

This study investigated the effectiveness of the AqAE on the VF and aquatic skills performance in the older children with spastic CP. Both the AqAE and the TPT training improved the VF and the aquatic skills performance in the older children with spastic CP. Furthermore; the AqET training was more beneficial in increasing the VF and the aquatic skills performance in the older children with spastic CP.

The AqET program proved effective in strengthening the weak muscles, increasing the range of motion, enhancing the circulation and lung function. [29] This can be attributed to the unrestrained movements, overcoming the gravitational constrains and the ease of use of muscles in patients with CP [30].

Improvement in the respiratory muscles strength and increased chest expansion are the main contributors to increased pulmonary functions in patients with CP after the rehabilitation program [31]. The obvious improvement in the pulmonary function in response to exercise training can be also attributed to increased patient’s ability to expand the chest wall since it is abnormally reduced in the patient with CP [32].

Previous study by Lai et al., reported that the aquatic therapy program for children with spastic CP can effectively improve gross motor function more than the conventional therapy even in children with very limited ability to perform activities [33].

Children with spastic CP benefit the more playful nature and the limited effort non-weight-bearing exercises performed during the aquatic therapy program that provides more pain-free activities compared with the conventional training programs [34].

The Aquatic therapy motivates children and encourages their engagement in the exercise program [35], reduces joint loading, minimizes the muscular fatigue and facilitates functional training in children with spastic cerebral palsy [36].

Children with spastic cerebral palsy are manifested with abnormal joints alignment and muscles contractures secondary to spasticity and muscle weakness, resulting in increasing activity-related pain and limitations that alter their physical performance [37].

The average increase of the WMA (152.23%), WSBM (150.96%), WTOT (147.72% %) in this study is higher than that found in the study of Declerck et al. [21] (16.85%), (17.35%), (17.15%) and Jorgić et al. [38] (26.73% %), (34.01%), (25.23% %) for WMA, WSBM, WTOT respectively.

The shorter study duration of six weeks as well as smaller samples numbers used in previous studies compared to longer (12-weeks duration training) and relatively larger sample size used in the current study, the differences in the participants' ages and the GMFCS levels as well as the training frequency can all explain these differences.

Improvements in evaluated variables within the aquatic training group can be attributed to the increased activity status achieved during the AqET program since hydrostatic pressure of the water reduces spasticity, reduces the lower limbs' joints compressive forces, improves blood circulation and enhances the motor function that cannot be easily performed on land in patients with CP [39]. Furthermore; water properties and buoyancy help supporting the child's weight, eliminating the compressive forces on the lower limbs' joints, and maintaining the anti-gravity position, so facilitates movements and activity performance compared with the on-ground status [40].

Limitations

Although positive results; certain limitations arise in this study. The small participants' number, involvement only of the GMFCS levels-I and II limits results generalizability, the inability to follow the double-blind study design was another limitation. Further studies are required to overcome these limitations.

Conflict of interest

Authors state no conflict of interest.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

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