The Effects of Aquatic Resistive Exercise on Adults with Cerebral Palsy

Deborah Thorpe, PT, Ph.D.[a] and Erin Griffith, SPT[b]

[a] Department of Allied Health Sciences, The University of North Carolina at Chapel Hill, Chapel Hill, NC, USA; dthorpe@med.unc.edu
[b] Department of Allied Health Sciences, The University of North Carolina at Chapel Hill, Chapel Hill, NC, USA; erin_griffith@med.unc.edu

Funding: This work was funded in part by an NIH Career Award (#5K23RR24054) and the American Academy of Cerebral Palsy and Developmental Medicine and by the Cerebral Palsy International Research Foundation's Ethel Hausman Clinical Scholars Award.

Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institutes of Health or the American Academy of Cerebral Palsy and Developmental Medicine.

Conflicts of interest: There are no conflicts of interest with this study or respective manuscript.

Manuscript Word Count: 2,766
References: 35
Tables: 5
Supplemental Tables: 1

Corresponding author of contact and reprint requests:
Deborah Thorpe, PT, Ph.D.
Division of Physical Therapy
Department of Allied Health Sciences
3006 Bondurant Hall, CB# 7135
The University of North Carolina at Chapel Hill
Chapel Hill, NC 27599-7135
Email: deborah_thorpe@med.unc.edu
Cell: 336-266-3101

Background

Cerebral palsy (CP) is the most common motor disability in childhood, with a prevalence of 3 per 1,000 children in the United States.[1,2] Cerebral palsy describes a group of disorders of movement and posture that are attributed to damage or malformation of the developing fetal or infant brain.[3,4] The etiology of CP affects muscle control and coordination, resulting in activity limitations and participation restrictions throughout the lifespan.

Children with CP present with abnormal reflexes, spasticity, muscle weakness, and contractures.[3,5,6] Resultant muscle imbalances and reductions in range of motion alter the amount and quality of their movements. These impairments can delay child growth and development by causing fatigue; joint and muscle pain; and difficulties with walking, feeding, swallowing, and speaking.[4]

As children with CP age, their existing impairments subject them to secondary conditions and a trajectory of functional decline. Cerebral palsy is not a static disorder, as its symptoms change over a person's lifetime. For adults, these changes commonly include fatigue, pain, depression, physical performance, and the musculoskeletal system at large.[5,7] Fatigue tends to correlate with decreased functional mobility for individuals with CP, such as those classified as Gross Motor Function Classification System (GMFCS) levels IV and V.[8,9] Yet the experience of pain seems to be widespread across individuals in all GMFCS levels.[5,10] Musculoskeletal pain is reported in 30-80% of adults with CP,[5] and the prevalence of joint pain and arthritis is twice that of their non-disabled peers.[10] Studies have shown that adults with CP have low bone mineral density (BMD) regardless of their ambulation history and are at greater risk for osteoporosis and fracture as they age.[11-14] Development of these secondary conditions perpetuates a cycle of physical inactivity and immobility that increases their risk for additional comorbidities.

Physical inactivity, paired with the age-related changes of CP, contributes to higher rates of comorbidities such as hypertension, hyperlipidemia, and obesity.[6,10,15] In turn, the presence of these specific comorbidities accelerates the development and appearance of metabolic diseases, including heart disease, stroke, and diabetes.[6,10] When tracking disease risk in adults with CP, Peterson et al[10] reported that higher levels of mobility impairment were strongly associated with chronic conditions, confirming the need for preventative intervention in this population.

Physical activity guidelines recommend that individuals with CP participate in aerobic and muscle-strengthening exercises at moderate-to-vigorous intensities.[16] However, because of comorbidities and impairments in muscle strength, range of motion, balance, and endurance, it is difficult for them to exercise at these intensities, especially non-ambulators classified as GMFCS levels IV and V. According to Morgan et al,[17] adults with CP who ambulate do so at slower speeds and with shorter stride lengths and greater energy expenditure as compared to their age-related peers. This combination of gait impairments makes them vulnerable to falls and balance dysfunction, which are associated with an early decline in walking ability.[17,18] Rehabilitation interventions for this population have traditionally focused on decreasing sedentary behavior through gait and balance training.[19] Land-based exercises are employed to delay functional decline in adults with CP, but the negative effects that gravity has on joint integrity, pain, and movement make some land-based exercises less suitable.[20,21]

Aquatic-based interventions offer an alternative environment where the effects of gravity are minimized. The unique properties of water give adults with CP more freedom to exercise at higher intensities.[22] Buoyancy enables decreased joint loading and weight-bearing by supporting an individual's body weight.[23] The amount of unweighting increases as more of their body is submerged and results in less stress on joints and decreased pain with movement. Buoyancy can assist in movement or be used as resistance, depending on the position and direction of movement. A body in water is subject to hydrostatic pressure that is proportional to the depth of the water and is equal in every direction. This property promotes lymphatic return and cardiovascular conditioning by forcing fluid from the extremities toward the chest.[23] Hydrostatic pressure and turbulence also create resistance that can increase the intensity of exercise and allow for strengthening in all planes of motion.[23] The warm water temperatures that are characteristic of a therapeutic pool (92°F-96°F) can facilitate pain relief and relaxation of spastic muscles, offering yet another advantage of aquatic-based interventions.[24]

Adults with CP have specific impairments in gait, balance, strength, and pain that could be mitigated by exercise in an aquatic environment, especially for those in GMFCS levels III-V. The purpose of this study was to establish the feasibility of a longitudinal aquatic exercise intervention and to evaluate the effects of aquatic resistive exercise on body mass index (BMI), lean muscle mass (LMM), BMD, health-related quality of life (HRQoL), physical activity level, pain, gross motor function, and strength in a sample of adults with CP classified across GMFCS levels I-IV.

Methods

Participants

In this quasi-experimental cohort study, participants were a convenience sample of 47 adults with CP ages 21 years and older. Thirty adults with CP completed a 12-week aquatic exercise program, and 17 adults with CP comprised a comparison group who received "attention" in the form of monthly phone calls from investigators and a fitness consult from DT. Inclusion criteria included functional use of at least one arm, ability to follow multiple-step instructions, intact cerebral function as evaluated by the oral or written Symbol Digit Modalities

Test,[25] and ability to communicate. Exclusion criteria were history of genetic disease, uncontrolled seizure disorder, no reliable means of communication, and IQ < 70. Specific exclusion criteria for participation in the aquatic intervention were tracheotomy or gastrointestinal tube, open wound(s), bowel and/or bladder incontinence, and chlorine and/or bromine allergies.

Human subjects research approval was given by the Office of Human Research Ethics at the University of North Carolina at Chapel Hill. Informed consent was obtained from each participant or their guardian prior to participation.

Procedure

All participants were assessed at baseline, 3 months post-baseline (immediately post-intervention), and at a 9-month follow-up (6 months post-intervention). The outcome measures and assessment schedule are listed in Table 1. Duration of assessment sessions were approximately 2-3 hours each. All testing took place at the General Clinical Research Center (GCRC) at the University of North Carolina at Chapel Hill.

Protocol for Aquatic Intervention

Aquatic group participants exercised under the guidance of an individual exercise trainer in a therapeutic pool heated between 86°F and 92°F, 3 times per week for 12 weeks. Exercise intensity was monitored using waterproof Polar Heart Rate (HR) Monitors[*] and was recorded every 15 minutes of the session. Goal target heart rate (THR) was calculated using the following formula: THR = 220 - age - 17 beats (adjustment for exercise in water) X 85%. For participants that entered the study on hypertensive medication, THR was calculated by noting their HR when they were working at exertion level #6 (tired: can still talk but slightly breathless and sweating)

[*] Polar Electro Oy, Professorintie 5, 90440 Kempele, Finland

on Borg's Rating of Perceived Exertion scale (Cardiovascular Endurance).[26] Their goal training HR zone (85% of max HR) was calculated from that HR. Participants on hypertensive medications had their blood pressure (BP) measured once per week immediately after they finished a high level of exercise (RPE = 5 or 6) to confirm that it was less than 220/100 and to ensure their THR ranges were set correctly. If a training effect occurred over the 12-week training period, RPE would decrease, even though the average heart rate (AHR) stayed within the target zone.

For each aquatic exercise session, an individual exercise trainer placed the Polar HR Monitor wrist monitor and chest band on the participant prior to entering the water. The participant's resting heart rate (RHR) was recorded. The participant exercised in a structured water session (Table 2) for approximately 45 minutes, performing combinations of the exercises (Table S1). Immediately after the participant completed their last exercise bout, the exercise trainer activated the Polar HR Monitor in "HR recovery mode" where the monitor would track HR recovery beats for 2 minutes. At the end of 2 minutes, the recovery beats were saved on the wrist monitor and the participant removed the wrist monitor and chest band. The exercise trainer then recovered and recorded the monitor's readings of average HR during the session, maximum HR during the session, and HR beats recovered at the end of the session.

Statistical Analyses

This study was a longitudinal, intervention, repeated measures design. Descriptive statistics were used to describe the population. Groups were assessed at baseline using the chi-square test for categorical variables (gender, GMFCS level, medical conditions, race, education, annual household income, and primary insurance) and Mann-Whitney U test for continuous variables (age, BMI, LMM, and BMD) to assure equality at baseline. A repeated measures

ANOVA determined changes over time between groups across all outcomes. A paired t-test with Bonferonni Correction assessed within-group changes across outcomes. Counts and percentages were used to establish participant recruitment success (# participants / # screened X 100) and compliance (# aquatic sessions attended / # offered X 100) with the intervention.

All statistical tests were performed at the .05 level of significance ($p < .05$). The Statistical Package for the Social Sciences statistical software version 27.0 (SPSS Inc, Chicago, Illinois) was used for quantitative analysis.

Results

Participants

One hundred and forty-two individuals were identified and screened for this study. One hundred individuals were deemed eligible and participated in the cross-sectional part of this study. Of those, 47 volunteered to participate in the intervention arm. Baseline descriptives of both groups are described in Table 3. There were 30 adults with CP (9 male, 21 female) with a mean age of 34.8 ± 12.9 years in the aquatic group. There were 17 adults with CP (12 male, 5 female) with a mean age of 29.2 ± 7.8 years in the comparison group.

There were no significant differences in age (p = .176), BMI (p = .634), LMM (p = .170), BMD (p = .250), GMFCS level (p = .605), medical conditions, race (p = .574), and education (p = .715) between the aquatic and comparison groups. However, the average age, BMI, BMD, and percentage of participants who pursued graduate education were higher in the aquatic group. A greater portion of participants in the comparison group had a history of fracture and osteoporosis. GMFCS levels I-IV were represented in both groups, with a higher percentage of individuals classified as GMFCS level I and a lower percentage of individuals classified as GMFCS level IV. The majority of both groups identified as white.

There were significant differences between the aquatic and comparison groups in gender ($p = .007$), annual household income, ($p = .019$) and primary insurance ($p = .037$). The aquatic group was largely female, while the comparison group was largely male. Over 30% of the aquatic group reported an annual household income of ≥ $50,000, and a considerable portion of the comparison group reported < $9,000 or an unknown value. A higher percentage of the aquatic group held private insurance, as compared to the comparison group who accessed more federally funded forms of insurance. Both groups attended all evaluation sessions, and the aquatic group achieved 100% attendance compliance for aquatic exercise sessions.

Between-Group Changes

At baseline, only the PADS showed a significant difference between groups, with the aquatic group having higher self-reported levels of physical activity ($p = .021$). The aquatic group demonstrated a greater improvement in GMFM dimension E scores from baseline to follow-up ($p = .002$). There were no significant differences in any other outcome measures between groups (Table 4).

Within-Group Changes

The aquatic group showed a trend for increasing BMD ($p = .050$) into the follow-up period. The aquatic group also showed significant improvements in GMFM dimension D scores from baseline to post-intervention ($p = .004$) and post-intervention to follow-up ($p = .031$), as well as in GMFM dimension E scores ($p = .000$ and $p = .013$, respectively). The aquatic group displayed significant gains in strength for right knee extensors ($t(29) = -2.09$; $p = .050$) and left knee extensors ($t(29) = -2.47$; $p = .020$) from post-intervention to follow-up. In addition, left knee flexors ($t(29) = -2.05$; $p = .050$) gained strength from baseline to post-intervention. (Data related to handheld dynamometry not shown in Tables 4 and 5). The comparison group exhibited a significant decrease in LMM from post-intervention to follow-up (p = .015) (Table 5).

Discussion

The participant compliance rate (100%) for the aquatic intervention group supported the hypothesis that adults with CP, ages 21 years and older and at differing functional levels want to exercise to improve their health and fitness. There were no recorded safety incidents or adverse effects during any aquatic exercise session. The study was high in man-power, with a 1:1 ratio of trainers and participants in the pool, but this was required for safety and we feel contributed to participant motivation that resulted in 100% compliance with attendance.

Though the only significant between-group change was an improvement in the aquatic group scores for the GMFM dimension E compared to the comparison group scores, the individuals in the intervention group did make significant within-group gains over time in the GMFM dimensions D and E, as well as a positive trend in BMD at follow-up. The positive changes in gross motor function are similar to the findings of several systematic reviews,[27,28] a case study on a young adult with CP,[22] and a case series on adolescents with CP[29] regarding the effects of aquatic exercise on individuals with spastic CP, ages 3-21 years. In the reviews,[27,28] most of the gross motor changes were seen in the GMFM dimensions D and E, and the studies with an intervention duration > 10 weeks and weekly frequencies of at least 2 times per week resulted in the most improvement and longevity in gross motor scores. In the case study by Thorpe et al,[22] after a 10-week, 3 times per week aquatic exercise intervention, the young adult with CP exhibited significant improvements in the GMFM dimensions D and E, average strength gains of 100% in most lower extremity muscle groups, and an increased gait velocity of 3 meters per minute.

The structure of aquatic exercise sessions in other studies resembles that of this study, with stretching, aerobic exercises, strengthening, gross motor activities, and various forms of ambulation in the water. It has been noted that aquatic interventions that include strengthening and aerobic exercises have the potential to improve gross motor function in children with CP, but little research has been published to support this claim in adults. The results of this study clarify the positive effects of aquatic exercise beyond the childhood years, affirming that it can be a lifelong mode of physical activity for those with CP. Significant changes in the GMFM domains of standing, walking, running, and jumping may prolong or enhance their participation in self-care, recreational, and leisure activities.

A few of the limitations of this study were the small sample size, lack of randomization, and unequal groups. It is difficult to compare individuals with CP without breaking them into subsets because of their heterogeneous clinical presentations, such as in GMFCS level and communication status. In an intervention study, this poses a challenge to attaining sufficient representation per group that allows statistical comparison and generalization of results. While the percentage of participants in each GMFCS level was similar between the aquatic and comparison groups of this study, the size and method of sampling caused variability between the groups and thus they were significantly different at baseline.

Strengths of this study were the 100% compliance rate of participants in the aquatic intervention, the feasibility of their participation, and the age and GMFCS level distribution among groups. Feasibility was established for young to middle-aged adults with CP of differing functional levels to engage in a moderate-intensity aquatic exercise program at a moderate weekly frequency for 12 weeks. Their age and motor capabilities did not prove to be a hindrance to their participation or their progress in the intervention. With documented improvements in individuals classified as GMFCS levels I-IV, it is suggested that this program's design was adequate in catering to various levels of motor control, thereby enabling all participants to engage in and benefit from aquatic exercise.

In conclusion, the results of this study show that a longitudinal aquatic exercise intervention is feasible and adverse effects are minimal in adults with CP classified across GMFCS levels I-IV. Resistive aquatic exercise produces a significant improvement in gross motor function and a trend toward improvement in BMD. However, further large-scale randomized controlled trials are needed to confirm the findings of this study and aid in the development of recommendations regarding frequency, duration, and intensity of aquatic-based strengthening programs for the aging CP population.

References

1. McGuire DO, Tian LH, Yeargin-Allsopp M, Dowling NF, Christensen DL. Prevalence of cerebral palsy, intellectual disability, hearing loss, and blindness, National Health Interview Survey, 2009-2016. *Disabil Health J*. 2019;12(3):443-451.
2. Arneson CL, Durkin MS, Benedict RE, et al. Prevalence of cerebral palsy: Autism and Developmental Disabilities Monitoring Network, three sites, United States, 2004. *Disabil Health J*. 2009;2(1):45-48.
3. Graham HK, Rosenbaum P, Paneth N, et al. Cerebral palsy. *Nat Rev Dis Primers*. 2016;2:15082.
4. Rosenbaum P, Paneth N, Leviton A, et al. A report: the definition and classification of cerebral palsy April 2006. *Dev Med Child Neurol Suppl*. 2007;109:8-14.
5. Turk MA. Health, mortality, and wellness issues in adults with cerebral palsy. *Dev Med Child Neurol*. 2009;51 Suppl 4:24-29.
6. Peterson MD, Gordon PM, Hurvitz EA. Chronic disease risk among adults with cerebral palsy: the role of premature sarcopoenia, obesity and sedentary behaviour. *Obes Rev*. 2013;14(2):171-182.
7. Van Der Slot WMA, Nieuwenhuijsen C, Van Den Berg-Emons RJG, et al. Chronic pain, fatigue, and depressive symptoms in adults with spastic bilateral cerebral palsy. *Dev Med Child Neurol*. 2012;54(9):836-842.
8. Moreau NG, Li L, Geaghan JP, Damiano DL. Fatigue resistance during a voluntary performance task is associated with lower levels of mobility in cerebral palsy. *Arch Phys Med Rehabil*. 2008;89(10):2011-2016.
9. Palisano RJ, Hanna SE, Rosenbaum PL, et al. Validation of a model of gross motor function for children with cerebral palsy. *Phys Ther*. 2000;80(10):974-985.
10. Peterson MD, Ryan JM, Hurvitz EA, Mahmoudi E. Chronic conditions in adults with cerebral palsy. *JAMA*. 2015;314(21):2303-2305.
11. Whitney DG, Alford AI, Devlin MJ, Caird MS, Hurvitz EA, Peterson MD. Adults with cerebral palsy have higher prevalence of fracture compared with adults without cerebral palsy independent of osteoporosis and cardiometabolic diseases. *J Bone Miner Res*. 2019;34(7):1240-1247.
12. Whitney DG, Kamdar NS, Ng S, Hurvitz EA, Peterson MD. Prevalence of high-burden medical conditions and health care resource utilization and costs among adults with cerebral palsy. *Clin Epidemiol*. 2019;11:469-481.
13. Mus-Peters CTR, Huisstede BMA, Noten S, Hitters MWMGC, van der Slot WMA, van den Berg-Emons RJG. Low bone mineral density in ambulatory persons with cerebral palsy? A systematic review. *Disabil Rehabil*. 2019;41(20):2392-2402.
14. French ZP, Caird MS, Whitney DG. Osteoporosis epidemiology among adults with cerebral palsy: findings from private and public administrative claims data. *JBMR PLUS*. 2019;3(11):e10231.
15. Ryan JM, Hensey O, McLoughlin B, Lyons A, Gormley J. Reduced moderate-to-vigorous physical activity and increased sedentary behavior are associated with elevated blood pressure values in children with cerebral palsy. *Phys Ther*. 2014;94(8):1144-1153.
16. Verschuren O, Peterson MD, Balemans ACJ, Hurvitz EA. Exercise and physical activity recommendations for people with cerebral palsy. *Dev Med Child Neurol*. 2016;58(8):798-808.

17. Morgan P, Murphy A, Opheim A, McGinley J. Gait characteristics, balance performance and falls in ambulant adults with cerebral palsy: an observational study. *Gait Posture*. 2016;48:243-248.
18. Opheim A, Jahnsen R, Olsson E, Stanghelle JK. Walking function, pain, and fatigue in adults with cerebral palsy: a 7-year follow-up study. *Dev Med Child Neurol*. 2009;51(5):381-388.
19. Levin I, Lewek MD, Feasel J, Thorpe DE. Gait training with visual feedback and proprioceptive input to reduce gait asymmetry in adults with cerebral palsy: a case series. *Pediatr Phys Ther*. 2017;29(2):138-145.
20. Kelly M, Darrah J. Aquatic exercise for children with cerebral palsy. *Dev Med Child Neurol*. 2005;47(12):838-842.
21. Gorter JW, Currie SJ. Aquatic exercise programs for children and adolescents with cerebral palsy: what do we know and where do we go? *Int J Pediatr*. 2011;2011:712165.
22. Thorpe DE, Reilly MA. The effect of aquatic resistive exercise on lower extremity strength, energy expenditure, functional mobility, balance and self-perception in an adult with cerebral palsy: a retrospective case report. *J Aquatic Phys Ther.* 2000; 8(2): 18-24.
23. Thorpe DE, Paul EE. Aquatic Therapy for Individuals with Cerebral Palsy Across the Lifespan. In: Miller F, Bachrach S, Lennon N, O'Neil M, eds. *Cerebral Palsy*. Cham: Springer International Publishing; 2019:1-20.
24. Irion JM. Aquatic properties and therapeutic interventions. In: Brody LT, Geigle PR, eds. *Aquatic Exercise for Rehabilitation and Training*. 1st ed. Champaign, IL: Human Kinetics; 2009:25-34.
25. Smith A. *Symbol Digit Modalities Test*. Los Angeles, CA: Western Psychological Services; 1982.
26. Stuckenschneider T, Rüdiger S, Abeln V, et al. Ratings of perceived exertion - a valid measure for monitoring light to vigorous exercise intensity in individuals with subjective and mild cognitive impairment? *Eur J Sport Sci.* 2020;20(2):261-268.
27. Roostaei M, Baharlouei H, Azadi H, Fragala-Pinkham MA. Effects of aquatic intervention on gross motor skills in children with cerebral palsy: a systematic review. *Phys Occup Ther Pediatr*. 2017;37(5):496-515.
28. Dolbow JD, Dolbow DR, Stevens SL, Hinojosa J. Restorative effects of aquatic exercise therapies on motor, gait, and cardiovascular function in children with cerebral palsy: a review of literature. *J Aquatic Phys Ther*. 2017; 25(1): 22-29.
29. Thorpe DE, Reilly M, Case L. The effects of an aquatic resistance exercise program on ambulatory children with cerebral palsy. *Pediatr Phys Ther*. 2005;13:21-35.
30. AACVPR. *Guidelines for Cardiac Rehabilitation and Secondary Prevention Programs-4th Edition*. 4th ed. Champaign, IL: Human Kinetics; 2003:288.
31. Wong DL, Baker CM. Pain in children: comparison of assessment scales. *Pediatr Nurs*. 1988;14(1):9-17.
32. Rimmer JH, Rubin SS, Braddock D, Hedman G. Physical activity patterns of African-American women with physical disabilities. *Med Sci Sports Exerc*. 1999;31(4):613-618.
33. Ware JE, Kosinski M, Keller SD. A 12-item short-form health survey. *Med Care*. 1996;34(3):220-233.
34. Russell D. *Gross Motor Function Measure Manual*. 2nd ed. Toronto, Canada: Easter Seals Research Institute; 1993.

35. Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther*. 1996;76(3):248-259.

List of Tables

Table 1. Assessment schedule for aquatic and comparison groups

Domain	Name of Variable	Description of Variable	Testing Session[1]
Screening	Cardiovascular and pulmonary function	American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) Screening[30]	1
	Mobility classification	Gross Motor Function Classification System (GMFCS)[9]	1
	Cerebral function	Symbol Digit Modalities Test[25]	1
Demographics	Health and function survey	Investigator-developed survey	1
Outcome measures for feasibility	Recruitment	% of total screened that participated	
	Compliance with intervention	% of times attending aquatic exercise	
Outcome measures for intervention	Pain	Level of pain from Wong Baker FACES Pain Scale[31]	1, 2, 3
	Activity level	Physical Activity and Disability Survey (PADS)[32]	1, 3
	Health-related quality of life (HRQoL)	SF-12[33]	1, 3
	Bone mineral density (BMD)	DEXA scan	1, 2, 3
	Lean muscle mass (LMM)	DEXA scan	1, 2, 3
	Body mass index (BMI)	DEXA scan	1, 2, 3
	Gross motor function	Gross Motor Function Measure (GMFM)[34]	1, 2, 3
	Leg strength	Manual muscle testing (handheld dynamometer)[35]	1, 2, 3

[1] Occasions: 1 = baseline, 2 = three months post-baseline (immediately post-intervention), 3 = nine month follow-up (six months post-intervention)

Table 2. Structure of aquatic exercise sessions

Component	Time (minutes)	Activity
Warm-up	5	Stretching on land and in water (hamstrings, Achilles tendons, and quadricep, gastrocnemius, and low back musculature)
Exercise	10	See Table S1
Rest period	1-3	Hydrate, breathe deeply
Exercise	15	See Table S1
Rest period	1-3	Hydrate, breathe deeply
Exercise	10	See Table S1
Cool-down	5	Hydrate, breathe deeply, slow walking, stretching in water (hamstrings, Achilles tendons, and quadricep, gastrocnemius, and low back musculature)

Table 3. Baseline descriptives of aquatic and comparison groups

	Aquatic Group (n = 30)	Comparison Group (n = 17)	
Gender	n (%)	n (%)	p^a
Male	9 (30.0)	12 (70.6)	.007*
Female	21 (70.0)	5 (29.4)	
Characteristics	X ± SD (Min-Max)	X ± SD (Min-Max)	p^b
Age (years)	34.8 ± 12.9 (21-65)	29.2 ± 7.8 (22-45)	.176
BMI (kg/m^2)	28.1 ± 6.5 (17.7-45.6)	27.3 ± 7.6 (15.4-45.3)	.634
LMM (kg)	41.0 ± 9.7 (23.3-64.2)	46.3 ± 13.5 (28.3-82.7)	.170
BMD (g/cm^2)	1.2 ± 0.2 (0.9-1.5)	1.1 ± 0.3 (0.7-1.6)	.250
GMFCS level	n (%)	n (%)	p^a
I	13 (43.3)	5 (29.4)	.605
II	9 (30.0)	5 (29.4)	
III	6 (20.0)	4 (23.5)	
IV	2 (6.7)	3 (17.6)	
Medical conditions	n (%)	n (%)	p^a
Fracture	10 (33.3)	9 (52.9)	.188
Osteoporosis	5 (16.7)	4 (23.5)	.566
Arthritis	7 (23.3)	4 (23.5)	.988
Hypertension	6 (20.0)	3 (17.6)	.844
Other medical condition	14 (46.7)	10 (58.8)	.423
Race	n (%)	n (%)	p^a
White	25 (83.3)	14 (82.4)	.574
Black	2 (6.7)	1 (5.9)	
Asian or Pacific Islander	3 (10.0)	1 (5.9)	
Caucasian Hispanic	0 (0)	1 (5.9)	
Education	n (%)	n (%)	p^a
Middle school (6-8 years)	1 (3.3)	0 (0)	.715
High school (9-12 years)	6 (20.0)	7 (41.2)	
College (13-16 years)	10 (33.3)	6 (35.3)	
Graduate school (≥ 17 years)	13 (43.3)	4 (23.5)	
Annual household income	n (%)	n (%)	p^a
< $9,000	5 (16.7)	5 (29.4)	.019*
$9,000 - $29,999	5 (16.7)	3 (17.6)	
$30,000 - $49,999	4 (13.3)	0 (0)	
≥ $50,000	11 (36.7)	3 (17.6)	
Not known	5 (16.7)	6 (35.3)	
Primary insurance	n (%)	n (%)	p^a
None	0 (0)	2 (11.8)	.037*
Private	15 (50.0)	4 (23.5)	
Medicaid	12 (40.0)	11 (64.7)	
Medicare	3 (10.0)	0 (0)	

p^a, chi-square test for categorical variables; X ± SD, mean ± standard deviation; min, minimum; max, maximum; p^b, Mann-Whitney *U* test for continuous variables; BMI, body mass index; LMM, lean muscle mass; BMD, bone mineral density; GMFCS, Gross Motor Function Classification System.
* significance: $p < .05$

Table 4. Between-group changes

	Aquatic Group (n = 30)			**Comparison Group (n = 17)**				
	Baseline X ± SD	Post- X ± SD	Follow-up X ± SD	Baseline X ± SD	Post- X ± SD	Follow-up X ± SD	p^a	p^b
BMD	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	1.1 ± 0.3	.214	.635
BMI	28.1 ± 6.5	28.1 ± 6.4	28.0 ± 6.8	27.3 ± 7.6	27.1 ± 7.8	26.7 ± 7.5	.710	.636
LMM	41.0 ± 9.7	41.3 ± 10.1	41.5 ± 10.4	46.3 ± 13.5	47.0 ± 14.7	45.8 ± 13.3	.122	.792
SF-12 PCS	43.8 ± 6.8	–	45.3 ± 7.3	43.3 ± 6.8	–	43.1 ± 7.3	.796	.587
SF-12 MCS	48.4 ± 6.8	–	47.9 ± 5.7	46.8 ± 6.8	–	47.2 ± 4.3	.441	.968
PADS	47.5 ± 26.1	–	43.2 ± 23.7	30.1 ± 20.0	–	24.4 ± 18.5	.021*	.230
FACES Pain Rating Scale	0.8 ± 1.0	0.5 ± 1.0	0.5 ± 0.9	0.9 ± 1.1	0.8 ± 1.2	0.5 ± 0.9	.711	.180
GMFM dimension D	68.8 ± 26.5	72.4 ± 26.8	69.2 ± 30.0	62.7 ± 31.9	63.6 ± 33.6	62.8 ± 33.7	.487	.053
GMFM dimension E	61.6 ± 29.7	67.8 ± 30.2	63.9 ± 31.7	56.0 ± 31.8	58.3 ± 31.8	56.8 ± 31.8	.544	.002*

X ± SD: mean ± standard deviation; p^a: independent samples t-test for baseline comparisons; p^b: ANOVA for group comparisons; BMD: bone mineral density; BMI: body mass index; LMM: lean muscle mass; SF-12: 12-Item Short Form Health Survey; PCS: physical health composite score; MCS: mental health composite score; PADS: Physical Activity and Disability Survey; GMFM: Gross Motor Function Measure; D: standing; E: walking, running, and jumping.
* significance: $p < .05$

Table 5. Within-group changes

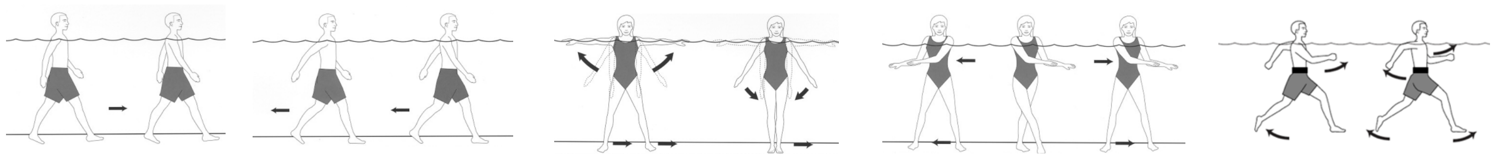
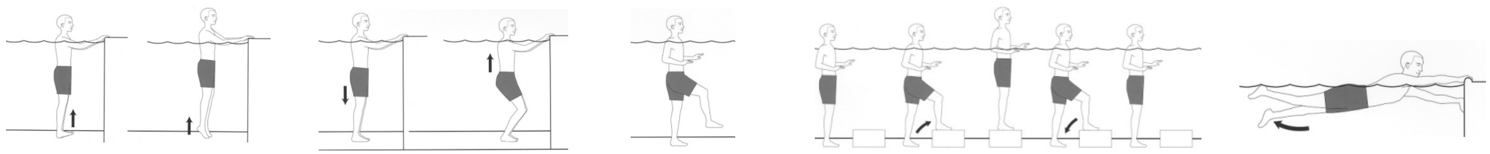
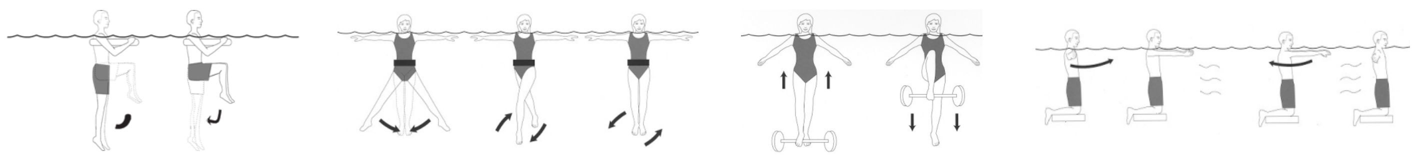
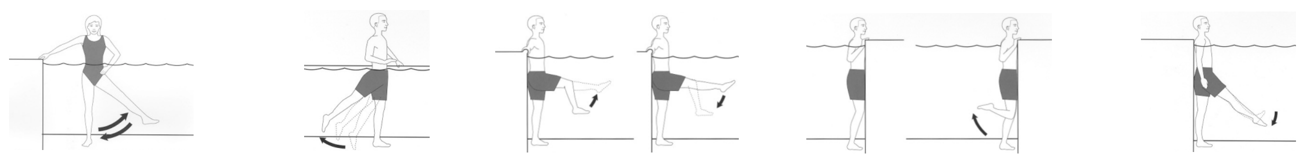
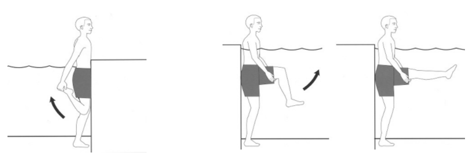
	Aquatic Group (n = 30)					Comparison Group (n = 17)				
	Baseline X ± SD	Post- X ± SD	Follow-up X ± SD	p^a	p^b	Baseline X ± SD	Post- X ± SD	Follow-up X ± SD	p^a	p^b
BMD	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.2	.106	.050*	1.1 ± 0.2	1.1 ± 0.2	1.1 ± 0.3	.438	.090
BMI	28.1 ± 6.5	28.1 ± 6.4	28.0 ± 6.8	.780	.458	27.3 ± 7.6	27.1 ± 7.8	26.7 ± 7.5	.523	.182
LMM	41.0 ± 9.7	41.3 ± 10.1	41.5 ± 10.4	.269	.566	46.3 ± 13.5	47.0 ± 14.7	45.8 ± 13.3	.264	.015*
SF-12 PCS	43.8 ± 6.8	–	45.3 ± 7.3	–	.200†	43.3 ± 6.8	–	43.1 ± 7.3	–	957†
SF-12 MCS	48.4 ± 6.8	–	47.9 ± 5.7	–	.678†	46.8 ± 6.8	–	47.2 ± 4.3	–	.824†
PADS	47.5 ± 26.1	–	43.2 ± 23.7	–	.464†	30.1 ± 20.0	–	24.4 ± 18.5	–	.128†
FACES Pain Rating Scale	0.77 ± 1.0	0.5 ± 1.0	0.5 ± 0.9	.315	.763	0.88 ± 1.1	0.8 ± 1.2	0.5 ± 0.9	.683	.236
GMFM dimension D	68.8 ± 26.5	72.4 ± 26.8	69.2 ± 30.0	.004*	.031*	62.7 ± 31.9	63.6 ± 33.6	62.8 ± 33.7	.564	.797
GMFM dimension E	61.6 ± 29.7	67.8 ± 30.2	63.9 ± 31.7	.000*	.013*	56.0 ± 31.8	58.3 ± 31.8	56.8 ± 31.8	.299	.266

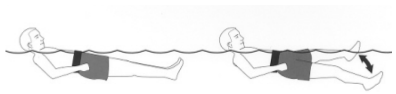
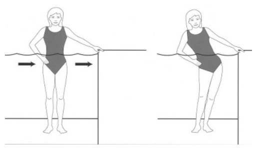
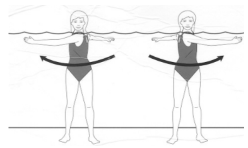
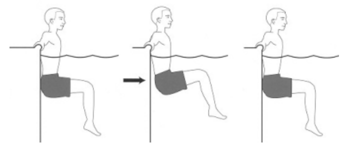
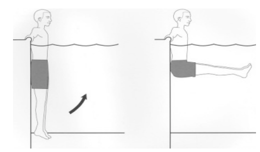
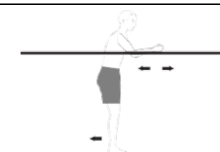
X ± SD: mean ± standard deviation; p^a: paired samples t-test for baseline to post-treatment; p^b: paired samples t-test for post-treatment to follow-up; BMD: bone mineral density; BMI: body mass index; LMM: lean muscle mass; SF-12: 12-Item Short Form Health Survey; PCS: physical health composite score; MCS: mental health composite score; PADS: Physical Activity and Disability Survey; GMFM: Gross Motor Function Measure; D: standing; E: walking, running, and jumping.

† baseline to follow-up

* significance: $p < .05$

Table S1. Aquatic exercises

Type of Exercise	Description of Exercise
Ambulation	 Walking forward; Walking backward; Walking sideways; Grapevine; Running
Compound for lower extremity	 Rock-n-roll; Squats; 1-Leg stand; Step-ups; Flutter kick
Deep water	 Bicycling; Scissors; Push-down; Kneel on kickboard
Isolation for lower extremity	 Hip abduction/adduction; Hip extension; Knee flexion/extension; Hamstring curl; Plantarflexion/dorsiflexion
Stretching	 Quadriceps stretch; Hamstrings stretch

Supine	 Hip abduction/adduction	 Bicycling			
Trunk	 Trunk lateral flexion	 Windmill	 Pelvic curl-up	 2-Leg lift	 Push kickboard