

ORIGINAL ARTICLE

Acute Aquatic Treadmill Exercise Improves Gait and Pain in People With Knee Osteoarthritis

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Abstract

Objective: To examine the acute effects of aquatic and land treadmill exercise on gait kinematics as well as the level of disease-specific and movement-related pain for individuals with osteoarthritis.

Design: Quasi-experimental crossover design.

Setting: Biomechanics laboratory.

Participants: Participants (N = 14; age, 43–64y) diagnosed with osteoarthritis at the knee (n = 12), osteoarthritis at the knee and ankle (n = 1), or osteoarthritis at the knee and hip (n = 1).

Interventions: Participants performed 3 exercise sessions separated by at least 24 hours in 1 week for each mode of exercise (aquatic treadmill and land treadmill).

Main Outcome Measures: Gait kinematics and pain were measured before and after each intervention.

Results: The angular velocity gain score during stance for left knee extension was improved by 38% after aquatic treadmill exercise ($P = .004$). Similarly, during swing, the gain scores for angular velocity were also greater for left knee internal rotation and extension by 65% and 20%, respectively ($P = .004$, $P = .008$, respectively). During stance, the joint angle gain score for left hip flexion was 7.23% greater after land exercise ($P = .007$). During swing, the angular velocity gain score for right hip extension was significantly greater for aquatic exercise by 28% ($P = .01$). Only the joint angle gain score for left ankle abduction during stance was significantly higher after land exercise (4.72%, $P = .003$). No other joint angle gain scores for either stance or swing were significantly different for either condition ($P = .06$ –.96). Perceived pain was 100% greater after land than aquatic treadmill exercise ($P = .02$). Step rate and step length were not different between conditions ($P = .31$ –.92).

Conclusions: An acute training period on an aquatic treadmill positively influenced joint angular velocity and arthritis-related joint pain. Acute aquatic treadmill exercise may be useful as a conservative treatment to improve angular speed of the lower-extremity joints and pain related to osteoarthritis.

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Osteoarthritis (OA) is a prevalent disease and is the most common form of arthritis in older adults.¹⁻³ People who suffer from lower-extremity OA are generally less active and have decreased physical conditioning and function, thereby decreasing their ability to perform daily activities and regular physical exercise.^{4,5} Although OA patients are commonly prescribed exercise regimens to promote physical activity and daily function, joint pain

often prevents the completion of these exercise regimens. Early termination of exercise programs because of knee pain prevents individuals from receiving the beneficial effects of aerobic training. Therefore, exercise programs that aim to decrease knee pain could potentially enable those with OA to perform longer, more strenuous workouts, resulting in increased cardiovascular fitness.⁴

Relative to land exercise, OA patients may complete longer, strenuous closed-chain exercises more easily in an aquatic environment, because joint loading and pain across affected joints are less.⁶⁻⁸ By increasing water depth, the percentage of body weight supported by the lower limbs can be incrementally decreased to accommodate various pain levels.^{9,10} Additionally, the warmth and

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pressure of water may decrease joint swelling and pain and improve locomotion.⁶ To date, no researchers, to our knowledge, have studied the effects of aquatic therapy training on lower-extremity kinematics, such as step length, joint angle, and joint angular velocity during overground walking in populations with knee OA. A clear understanding of the effect of acute aquatic therapy on lower-extremity kinematics could help clinicians decide when and how to use aquatic therapy in treating OA patients.

Previous research examining the progressive decline of kinematic gait parameters on land in patients with OA has revealed specific changes. Walker et al¹¹ used electrogoniometers to examine the minimum and maximum joint angles of the knee during various functional movements (walking on a level surface, ascending and descending a slope, etc) in 50 patients with OA of the knee and 20 age- and sex-matched controls. The researchers observed that OA patients displayed only 70% to 80% of normative knee flexion when compared with the control group ($P=.004$). Their results were supported by Hinman et al,⁶ who observed that OA patients walked slower and had 6° less peak knee motion than healthy subjects. These kinematic observations have led to the conclusion that changes in knee angle could be a strategy used by OA patients to reduce joint movement, therefore less pain is felt during weight-bearing activities. Thus, an examination of knee (and other lower-extremity joints) angle changes after aquatic therapy would be beneficial for a greater understanding of the functional effects of treatment.

With progressive worsening of OA, changes in gait kinematics are often accompanied by progressive worsening in pain.¹²⁻¹⁵ Astephen et al¹⁶ studied differences in self-reported pain and function among 3 groups: asymptomatic participants, moderate OA, and severe OA. All pain and function scores were worse in the moderate group than the asymptomatic group. The severe group also demonstrated worse scores in pain and function than the moderate group. These previous findings in the literature indicate the importance of including a measure of pain for studies examining the effectiveness of physical therapy treatments for OA patients.

The gait and pain alterations in OA patients noted in the previous literature may be precursors for pathologic alterations and would seem to be important variables to examine in an aquatic therapy study aimed at improving mobility. A greater understanding of these alterations may prove useful for the prescription of conservative treatments of OA and the prevention of OA progression. The present study examined the effects of short-term underwater treadmill exercise on gait kinematics, mobility, and perception of pain in OA patients. We hypothesized that there would be some joint kinematic, step length, and step rate differences during gait after aquatic treadmill when compared with land treadmill exercise. Further, we expected pain levels would decrease after the aquatic treadmill condition.

A comparison of treatments (aquatic vs land treadmill exercise) was necessary to establish a control condition and to determine the acute effectiveness of aquatic therapy on gait kinematics and pain.

Methods

All participants read and signed an informed consent form approved by the university institutional review board. All

List of abbreviations:

OA osteoarthritis

diagnoses were made by a local rheumatologist and were confirmed for definite OA based on a diagnostic algorithm.¹⁷ Additionally, participants had to be over 35 years of age, able to walk a city block (without the use of an ambulatory assistive device), and walk up stairs in a reciprocal manner. Participants were excluded if they currently exercised on an aquatic treadmill, had intra-articular corticosteroid injections in the past month, or reported any neuromuscular disease, cardiovascular disorders, surgeries to the lower limb (except for exploratory arthroscopy), lavage of knee joint, partial meniscectomy, or synovial fluid replacement therapy at least 1 year prior to entry into the study.

This study used a quasi-experimental crossover design to address the study purpose. Each participant completed 3 exercise sessions on an aquatic treadmill (fig 1; HydroWorx 2000^a) and on a land treadmill (Nordic Track 9600^b). The 3 exercise sessions in each condition were separated by at least 24 hours and completed within 1 week. The order of exercise mode (aquatic treadmill, land treadmill) was randomly assigned and separated by 1 rest week (table 1).

The amount of walking for each exercise bout was 20 minutes and consisted of four 5-minute stages at 0° incline (see fig 1). The first stage required participants to walk at a self-selected pace they considered comfortable. The second stage was .13m/s

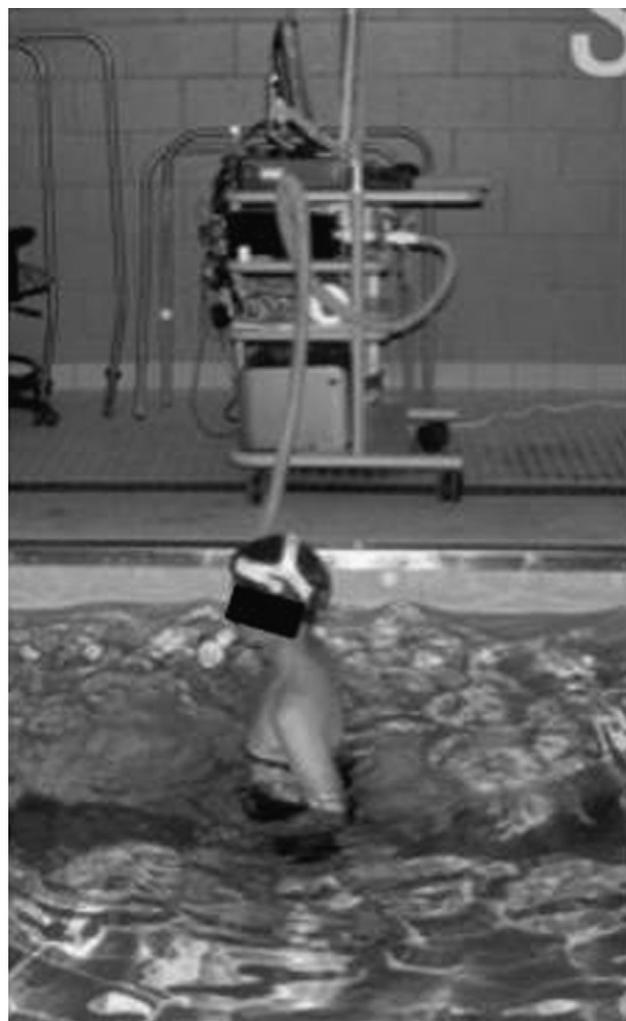


Fig 1 Experimental setup for the aquatic treadmill mode.

Table 1 A sample protocol for a participant

Week 1	- Pretesting with gait analysis, and VAS pain scales (baseline) - Three 20-min exercise sessions (separated by 24h) on aquatic treadmill - Posttesting with gait analysis, and VAS pain scales (follow-up)
Week 2	- Rest, no exercising outside of regular routine
Week 3	- Pretesting with gait analysis, and VAS pain scales (baseline) - Three 20-minute exercise sessions (separated by 24h) on land treadmill - Posttesting with gait analysis, and VAS pain scales (follow-up)

Abbreviation: VAS, visual analog scale.

(.30 miles/h) faster than the self-selected pace, and the third stage was .26m/s (.60 miles/h) faster than the self-selected pace. During the fourth stage, speed was matched to the first stage (fig 2). These increments in speed were intended to achieve a moderate to somewhat hard rating of perceived exertion, as evidenced in previous work using aquatic treadmills.⁸ Participants performed the aquatic treadmill exercise at a water depth equal to the xiphoid process. The temperature of the water was 30°C (86°F)⁶ with air temperature set at 24°C (75.2°F). The same protocol was completed for the land treadmill exercise in the same room.

Gait kinematics

Participants visited the biomechanics laboratory a total of 4 times: at least 24 hours before beginning the exercise week and within 24 hours of completing the final exercise session for each mode (aquatic or land) of exercise (table 2). Three-dimensional kinematics were assessed using a motion analysis system (Vicon MX system[©]). Participants walked 4 times at their preferred speed over a flat, straight, 10-m course using their walking shoes. Seven Vicon T-20 cameras sampling at 100Hz tracked 16 retro-reflective markers placed on the skin according to the lower-extremity plug-in gait model provided by Vicon. Markers were placed on the second toe, heel, lateral malleolus, midshank, lateral aspect of the knee, mid thigh, anterior superior iliac crest, and posterior superior iliac crest for both lower limbs. The 3-dimensional position data were filtered using a Visual3D^d low-pass Butterworth filter with a cutoff frequency of 8Hz.

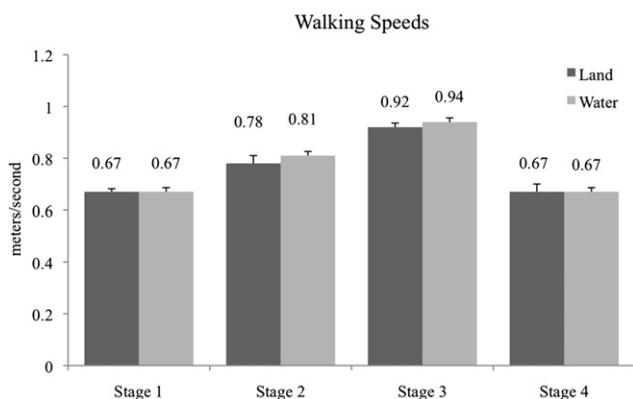


Fig 2 Average walking speeds at different stages for land and water conditions.

Table 2 Subject characteristics and OA assessment information

No.	Sex	Age (y)	Height (cm)	Mass (kg)	Involved Limb	Duration (y)
1	M	62	188	76.9	L knee	24
2	F	60	173	77.0	L and R knees	3
3	F	46	180	104.5	L knee	15
4	F	64	172	100.9	L and R knees	7
5	M	63	178	108.9	L knee	15
6	F	70	167	106.4	L knee	19
7	F	55	163	59.1	L knee	3
8	F	61	157	90.9	R knee	9
9	F	63	175	115.9	L and R knees	9
10	F	57	163	79.1	L and R knees	9
11	F	43	163	145.5	L and R knees	5
12	F	60	160	77.3	L and R knees	6
13	F	64	160	77.0	L and R knees	7
14	F	61	168	113.6	L knees	5

Abbreviations: Duration, duration since diagnosis; F, female; L, left; M, male; R, right.

On average, 6 consecutive steps from a single trial for each limb were used to calculate step length, step rate, and kinematics for each participant. Maximum and minimum joint angles and angular velocities of the hip, knee, and ankle were calculated for stance and swing phases from the position data using the Visual3D.

Pain scale

The perception of joint pain was assessed before the completion of gait analysis using a continuous visual analog scale, which has been reported as a reliable assessment of pain.¹⁸⁻²⁰ The scale was 12cm in length and was modeled after pain scales described by Carlsson.¹⁸ The left end of the scale was labeled no pain and the right end was labeled very severe pain. Written instructions were provided to each participant before they rated their pain that read, “please mark the line to indicate the arthritis-related joint pain that you have felt during the past week; the farther to the right, the more discomfort/pain you feel.” The pain scales were analyzed by measuring (mm) the distance from the left of the scale to the vertical mark drawn by each participant. All pre- and postexercise pain scores were averaged separately to yield a single mean pain score to represent the pain felt 1 week before and the week of exercise for each treadmill condition.

Statistical analyses

Self-selected treadmill speeds for the aquatic and land treadmills were compared with a paired-samples *t* test, and arthritis history information (eg, time since diagnosis) was analyzed descriptively. Significant differences for treadmill speeds were based on an alpha level set at .05. The independent variable in this study was mode of exercise (aquatic treadmill or land treadmill), and the dependent variables were gait kinematics (maximum and minimum joint angles and angular velocity, step length, and step rate) and perceived pain. A gain score was computed and used for statistical comparisons between conditions. In the present study, positive gain scores indicate that posttest scores are greater than pretest scores.

The nonparametric Wilcoxon signed-rank test was used to compare gait kinematics and perceived pain scores between

conditions. Significant differences for pain scores were based on an alpha level set at .05, and the sequential Bonferroni correction²¹ was made for the multiple kinematic comparisons. To help clinicians better interpret any significant or nonsignificant results, the median difference in gain scores between conditions and their 95% confidence intervals were calculated.

Results

Fourteen participants who responded to the request for volunteers met the inclusion and exclusion criteria. Physical characteristics and arthritis history for the participants are reported in table 2.

Pairwise comparisons of the self-selected speeds during exercise indicated they were not different between aquatic (.76±.24m/s) and land (.80±.26m/s) treadmill exercise ($P=.13$) (see fig 2). The descriptive results from the arthritis history questionnaire revealed that, on average, the amount of time between diagnosis and testing in our laboratory was 7.9±6.7 years and that the knee was the primary arthritic joint (see table 1).

Maximum and minimum joint angles and angular velocity

Maximum and minimum joint angle and angular velocity gain scores significantly differed, as shown in table 3. The angular velocity gain score during stance for left knee extension was 38.1% greater after aquatic treadmill exercise ($P=.004$) (see table 3). Similarly, during swing, the gain scores for angular velocity were also greater for left knee internal rotation and extension by 65% and 20%, respectively ($P=.004$, $P=.008$, respectively) (table 4). During stance, the joint angle gain score for left hip flexion was 7% greater after land exercise ($P=.007$) (see table 4). During swing, the angular velocity gain score for right hip extension was significantly greater after aquatic exercise by 28% ($P=.01$) (see table 4). Only the joint angle gain score for left ankle abduction during stance was significantly higher after land exercise, by 4.72% ($P=.003$) (see table 4). No other joint angle or angular velocity gain scores for either stance or swing were significantly different ($P=.06-.96$).

Perceived pain

Perceived pain was reduced by 100% after aquatic treadmill exercise compared with land treadmill exercise ($P=.02$) (table 5).

Step rate and length

Step rate and step length gain scores were not different between conditions ($P=.31-.92$).

Discussion

Self-selected speeds during aquatic and land treadmill exercise were not different (see fig 2). Barela and Duarte²² observed a difference in self-selected speeds during walking in a pool (.49m/s) versus walking on land (1.2m/s) in a group of healthy older adults. The disparity between studies is likely related to the different modes of exercise used. Walking on an aquatic treadmill, as performed in the present study, does not require the entire body to be displaced in the water, only the body segments required to move. In contrast, walking in a pool requires the entire body plus segments to be moved. Displacement or movement of the body produces an extra nonlinear increase in fluid drag²³ and a decrease in walking speed. Numerous aquatic treadmill studies have reported similar energy requirements during matched walking speeds in water and on land,²⁴⁻²⁷ and 1 previous study has reported similar preferred walking speeds between environments,⁸ which supports the results of the current study.

It is also important to note that the current study's participants were all diagnosed with OA (a population that typically exhibits slower walking speeds on land),^{5,14} while the Barela and Duarte study²² used a healthy, older adult population free from any musculoskeletal disease. Furthermore, Barela and Duarte²² observed that when walking in water at the level of the xiphoid process, older adults displayed a 14.3% decrease of the initial peak and a 9.8% decrease in the second peak vertical ground reaction force when compared with walking on land. Additionally, impact force values were 54% lower compared with walking on land. The reduction of these forces when walking underwater is likely attributed to buoyancy; and as a result, walking on an aquatic treadmill may prevent larger (more harmful) impact forces on the joints of individuals with OA.²² Because of abnormal joint loads and pain associated with OA, our participants may have had a more difficult time walking on a land than water treadmill. The findings of the current study may further support the use of an aquatic treadmill for improving exercise quality and quantity for patients with OA. Our gait kinematic values were consistent with previous research measuring joint kinematics of patients with OA.^{11,13,28} For example, Walker et al¹¹ reported a knee extension angle of 177°, which is consistent with our knee extension values (171°). Huang et al²⁹ reported a hip extension angle during stance of 170°, which is also consistent with our hip extension values (165°).

Table 3 Knee, ankle, and hip kinematic variables significant at the .05 level and the 95% confidence intervals

Comparisons	P	Sequential Bonferroni	
		Correction Value	95% Confidence Interval
Land vs aquatic stance maximum angular velocity for left knee (sagittal)	.004	.05/8 = .006	60.80 (29.10 to 88.20)*
Land vs aquatic swing minimum angular velocity for left knee (transverse)	.004	.05/7 = .007	-125.00 (-190.00 to -52.60)*
Land vs aquatic swing maximum angular velocity for left knee (sagittal)	.008	.05/6 = .008	62.40 (20.60 to 109.00)*
Land vs aquatic stance maximum angular position for left ankle (frontal)	.003	.05/11 = .005	9.75 (3.89 to 19.80)*
Land vs aquatic stance maximum angular position for left hip (sagittal)	.007	.05/6 = .008	9.88 (3.23 to 15.20)*
Land vs aquatic swing minimum angular velocity for right hip (sagittal)	.010	.05/5 = .010	-28.90 (-48.70 to -11.20)*
Land vs aquatic stance maximum angular position for left hip (sagittal)	.007	.05/6 = .008	9.88 (3.23 to 15.2)*

* Significantly different from aquatic exercise, $P<.05$.

Table 4 Significantly different maximum and minimum joint angular velocity and joint angle values during swing and stance

	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Maximum joint angular velocity (deg/s, mean ± SD) for the stance phase of gait						
Knee (sagittal)						
Left	207.0±47.3	226.0±88.7	251.0±36.2	188.0±51.4	44.3±57.4	-23.7±58.8*
Minimum joint angular velocity (deg/s, mean ± SD) for the swing phase of gait						
Hip (sagittal)						
Right	107.0±22.6	120.0±34.8	128.0±17.3	110.0±26.6	20.4±26.9	-9.3±41.0*
Knee (transverse)						
Left	201.0±95.4	224.0±107.0	293.0±109.0	181.0±88.8	91.4±93.9	-27.6±56.2*
Maximum joint angular velocity (deg/s, mean ± SD) for the swing phase of gait						
Knee (sagittal)						
Left	299.0±72.1	315.0±71.1	337.0±33.7	292.0±74.0	38.1±76.7	-25.5±47.1*
Maximum joint angles (deg, mean ± SD) for the stance phase of gait						
Hip (sagittal)						
Left	167.0±7.2	165.0±7.2	161.0±4.8	171.0±8.7	-6.3±6.2	3.0±8.8*
Ankle (frontal)						
Left	173.0±7.4	167.0±9.5	170.0±4.2	172.0±6.7	-4.3±3.0	4.9±11.9*

NOTE. Values were calculated before (pre) and after (post) aquatic and land treadmill exercise. The difference between post- and prevalues (gain) for the left and right legs are displayed for the ankle, knee, and hip joints.

* Significantly different from aquatic exercise, $P < .05$.

The results of this study support our hypothesis that some kinematic differences would occur after aquatic exercise. Hip, knee, and ankle kinematics were affected over the course of the acute training periods with most changes observed to the left limb (see table 4). It may be that we observed more changes to the left limb compared with the right because there were more subjects with left-sided OA than right-sided OA (see table 1). For example, angular velocity gain scores for left knee extension during stance, left knee internal rotation during swing, and left knee extension during swing were significantly greater after aquatic exercise versus land exercise. Similarly, angular velocity gain scores for left ankle abduction during stance and right hip flexion during swing were also greater after aquatic exercise compared with land exercise. The increases in angular velocity are important, because the values may be closer to those of a healthy population (maximum knee angular velocity during swing = 403°/s)³⁰ and may show evidence of improvements in the functional patterns of use of the knee during walking. We observed maximal knee angular velocity during swing after aquatic exercise to be 337°/s. These findings suggest aquatic therapy may be more beneficial than traditional land-based exercise for improving the angular velocity of a joint, particularly the knee, hip, or ankle, which may be critical for restoring gait quality and preventing falls. Although improving dynamic balance was not a main goal of the current study, tripping over

obstacles is the chief cause of falls among older adults, and increasing angular velocity of the knee is important when avoiding loss of balance and/or falling.³¹

The mechanism for increasing angular velocity could be because of the unique environment of the aquatic exercise; there is an increased resistance to movement as a result of the drag force exerted by water against the segments of the body.²² The aquatic environment, in comparison with the terrestrial environment, could perhaps strengthen the neuromuscular aspects that affect lower-limb kinematics to a greater degree, in an effort to overcome this increase in fluid resistance that influences joint angular velocity. Clinically, these benefits of underwater treadmill exercise (ie, the warmth and pressure of the water and unloading of the joints) could be used to improve lower-limb range of motion and angular velocity of patients with OA.

Although hip flexion gain scores were higher for land exercise, we believe this result may indicate that compensatory deviations at the hip may take place to overcome limited range of motion at the knee and ankle after exercising on land.³² Participants may adopt an exaggerated hip flexion pattern when walking to overcome problems caused by the disease. This contention requires further testing using a more complete biomechanical analysis that includes joint torques and powers.

Although we hypothesized that step length and step rate would be altered after aquatic exercise, our results did not support these

Table 5 Pain scores for aquatic and land treadmill exercise measured with a visual analog scale

Score	Pretest		Posttest		Gain	
	Aquatic	Land	Aquatic	Land	Aquatic	Land
Pain scores (mean ± SD)	37.2±25.0	40.0±24.1	25.5±25.2	37.4±23.4	-15.4±20.7	0.1±19.2*

NOTE. Values are mean ± SD. Calculated before (pre) and after (post) aquatic and land treadmill exercise. The differences between post- and prevalues (gain) are also displayed. Gain scores were computed as the difference between pretest and posttest values. A negative gain score indicates that pain was reduced after exercise, while a positive score indicates pain was increased after exercise.

* Significantly different from aquatic exercise, $P < .05$.

changes. Despite significant differences found in joint velocity and angle gain scores between land and aquatic exercises, no differences were detected between step rate and step length. In a similarly designed study, Denning et al⁸ observed that mobility, based on Timed Up & Go scores, improved after an acute bout of aquatic training as opposed to land training, but they also found no differences between stride rate and stride length ($P = .16$). These similar findings could infer that neuromuscular aspects of the body and balance improved in the short time period, rather than walking speed and step length. It should be noted that the present study was not designed to encourage walking speed. The participants were asked to walk at their own comfortable speed; had the study also included another condition in which participants were asked to walk as fast as possible, there may have been changes observed in step rate and step length.

The results of this study support our hypothesis that patients with OA of the knee might have less arthritis-related joint pain by training on an aquatic treadmill as opposed to a land-based treadmill. Knee pain relief may allow completion of exercise regimens that would enable patients with OA to increase the length and quality of workouts. Moreover, this improvement in higher aerobic training could result in higher cardiovascular fitness and improved physical conditioning. Our results are consistent with Denning,⁸ who observed that perceived joint pain was less immediately after aquatic treadmill versus land treadmill exercise. Others, such as Huang,²⁹ Patrick,³³ and colleagues did not observe changes in pain after aquatic exercise. This disagreement among studies may be because of differences in several factors, such as how and when an assessment was administered, type of assessment, and type of aquatic exercise (aquatic treadmill versus aquatic exercises targeted at upper- and lower-body movements). The current study and the study conducted by Denning⁸ targeted specific pain only related to knee OA, while others examined general pain. While it is beyond the scope of this study to ascertain the exact mechanism for the reduction in pain, previous authors have concluded that the benefits may be related to buoyancy, warmth, and pressure of the water.

Study limitations

Regarding limitations of this study, patients with OA completed measurements before and after only 3 exercise sessions. Increasing the length of the training period could produce alternative outcomes for gait kinematics. While this was a limitation, 3 exercise sessions were apparently long enough for neuromuscular changes to take place, and these results are supported by Denning et al,⁸ who demonstrated that oxygen consumption and rating of perceived exertion measures were level after 3 exercise sessions on an aquatic treadmill, which may suggest this acute amount of time was sufficient for familiarization. Leardini et al³⁴ recommend that motion about axes other than the flexion/extension axis should be observed carefully, because artifact, such as skin motion, particularly at the thigh, can produce false effects with magnitudes comparable with the amount of motion actually occurring at the joint. Therefore, because of the effects of soft tissue artifact, we suggest interpreting the results of the coronal and transverse plane kinematics section with caution. The acute assessment used in this study is valuable, because the outcomes of this study could help clinicians decide when and how to use aquatic treadmill therapy in treatment of patients with knee OA, particularly if the goal is to improve OA related pain and/or gait kinematics.

It should be noted that in addition to kinematic and self-reported measurements, participants in the present study gave subjective comments and all had preference for the aquatic treadmill over the land treadmill. Generally the participants stated that they enjoyed how they felt in the water and were interested in continuing the aquatic exercise after ending the study. However, because of the lack of aquatic treadmills in the community at the time, most participants were unable to continue the training, which could be considered a temporary shortcoming for aquatic treadmill training.

Conclusions

The present study demonstrated that an acute training period on an aquatic treadmill tended to increase select joint angular velocities and decrease arthritis-related joint pain. Although some acute effects of training (ie, pain, angular velocity) improved after aquatic training compared with land, it is unclear whether or not aquatic exercise is a better long-term alternative to land exercise, because further longitudinal research is needed to examine gait kinematic changes after an increased training period of aquatic exercise. Clinicians may use aquatic treadmill training as an acutely effective nonpharmacologic, conservative modality to treat some knee OA symptoms, although additional research is needed to determine the most efficient training protocols and clarify further the mechanism by which gait kinematics and pain are improved for patients with knee OA.

Suppliers

- HydroWorx, 1420 Stoneridge Drive, Middletown, PA 17057.
- ICON Fitness, 1500 South 1000 West, Logan, UT 84321.
- Vicon Motion Systems, 7388 South Revere Parkway Centennial, Centennial, CO 80112.
- C-Motion Inc, 20030 Century Boulevard, Germantown, MD 20874.

Keywords

Arthritis; Biomechanics; Pain measurement; Rehabilitation

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