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ORIGINAL

Gait Pattern of Hemiplegic Patients with Swimming Aqua-noodles

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Objective: The purpose of this study was to investigate the effects of aqua-noodles on the practice of underwater walking in patients with hemiplegia.

Method: After an oral explanation and signing an IRB approved consent form 10 participants (66.8±10.75 yr, 165.3±8.79 cm, 73.6±46 kg) agreed to participate in this study. Each of the participants was required to walk with the aqua noodles and without the aqua-noodles in a swimming pool. Each participant was asked to walk a distance of 5 m a total of 10 times, 5 with and 5 without the aqua-noodles. The depth of the swimming pool was at 1.3 m, approximately chest height. The following variables were calculated for analysis; height of the knee (m), knee joint ROM (°), ankle joint ROM (°), knee joint maximum angular velocity (°/sec), and ankle joint maximum angular velocity (°/sec).

Results: First, there was a significant increase in time (s) for the maximum knee height to reach as well as the maximum knee height (m) increased when the participant used the aqua-noodles. Second, there was a statistically significant decrease in stride length when the aqua-noodles were used.

Conclusion: This study helps to verify that the effect of underwater walking exercise can provide a suitable walking exercise environment. The results of this study provide systematic scientific information about how walking in water can be used for the rehabilitation of patients and the elderly.

Keywords: Hemiplegia patients, Aqua-walking, Aqua-noodles

INTRODUCTION

Exercise is well known as an elixir to maintain health or to restore health (Chang, 2018). One of the requirements for exercise is the ability to move around by walking. Patients with degenerative arthritis or those with hemiplegia have many difficulties walking and thus, have a high risk of developing metabolic syndromes such as obesity, diabetes and hypertension, because they cannot participate in exercise. This lack of physical activity further leads to a decrease in physical fitness, loss of muscle mass, fat accumulation, and increased abdominal fat (Rikli & Jones, 1997; Landers, Hunter, Wetzstein, Bamman, & Wiensier, 2001; Shephard, 1997). Stroke resulting in hemiplegia is reported to account for the highest number of single-disease mortality in Korea (Oh & Kwon, 2018). Coupled with severe limitations to gait can cause balance disorders and falling with can further weaken paralytics daily function (Campbell, Ashburn, Pickering, & Brunett, 2001).

Aqua-therapy is a safe and effective exercise for people with chronic diseases (Jetter & Kadlec, 1985; Wilson, 1984), such as obesity and osteoarthritis (Park, Kim, & Kim, 2006). The buoyancy in the water makes the movement of the limbs easier and improves the coordination of the upper and lower limbs, which is especially helpful for hemiplegic patients (Koury, 1996). In a study (Jeong, Kim, & Cheon, 2011) about the effect of walking in water, the results show that the hemiplegia group

Table 1. Characteristics of the participants

Participant	Gender (F/M)	Age (yrs)	Height (cm)	Weight (kg)	Hemiplegia On set (Month, Year,)
a	M	66	165	77	July, 2004
b	M	70	166	72.5	March, 2008
c	M	61	165	78.5	September, 1996
d	M	57	165	71	January, 2002
e	M	82	160	59.9	April, 2008
f	M	63	180	85	March, 1997
g	M	47	180	103.5	September, 2010
h	F	71	161	64	September, 2000
i	F	77	152	59	December, 1996
j	F	65	159	65.7	September, 1999
Mean ± St. Dev.	10	66.8±10.75	165.3±8.79	73.6±46	

who performed aquatic exercises demonstrated more coordinated walking then the group that performed land based exercises. Similarly, Kim et al. (2006) showed improved walking, i.e. faster walking speed, longer stride length, and less vertical center position displacement, after aqua-based exercises. In addition, aqua-based exercise not only increases walking speed, but also improved endurance and balance (Lee & Kim, 2009).

In order to improve the walking of patients with hemiplegia, various aids such as a variety of orthoses and walkers (Constantinescu, 2006) are used in land based gait training. Kuan et al. (1999) reported that using a cane help normalize walking patterns by aiding in balance and reducing stress and strain on the effected limbs. Likewise, orthosis are used to reduce the movement and height of the person's center of gravity during walking to add stability (Joyce & Kirby, 1991).

Research shows that aqua based rehabilitation exercise programs are indispensable for underwater walking practice, especially for patients with hemiplegia, as their range of motion of the lower extremity joints on the ground is limited. With the added support of using aqua-noodles during gait for balance, we expect that walking in water with aqua-noodles will produce more normalized walking patterns and help those suffering from hemiplegia. Therefore, the purpose of this study is to investigate if the hemiplegia participants gait pattern improves due to the hypothesized increase in the movement ability of the participant and thus, therefore, a corresponding increase in joint range of motion for the ankle and knee when using aqua-noodles.

METHODS

1. Participants

Ten patients (7 males, 3 females) with cerebral palsy due to hemiplegia (for longer than 6 months) were recruited for this study. Each of the participants had to have the ability to exercise under supervision in water and have a stable heart rate and blood pressure. The participant demographics are shown in Table 1.

2. Experimental equipment

For the underwater motion capture 1) image analysis equipment, 2) control point frame, 3) analysis tools, were installed. The video recording equipment consisted of 3 digital video cameras (SONY HDR-XR! 60) with 60 frames / sec and specially manufactured waterproof equipment from Japan SPK-HCE for underwater shooting. The control point frame (size; front and rear (3 m), left and right (1 m) and vertical (2 m) models) was used to set up control volume for the 3D reconstruction with the image analysis software (Kwon 3D ver 3.1, Visol Inc.).

3. Testing procedure

Prior to any measurement the testing and all related procedures were explained and each signed an IRB approved consent form to participate. To ensure that the participants were familiar walking in the water with the aqua-noodles they had a 1 month familiarization period. Each of the participants performed both aqua walking (i.e. control condition) and walking with the aqua-noodles.

On the day of the experiment, 3 video cameras (60 frames / sec) and an underwater light were installed at the position where the experiment section could be taken for underwater shooting. The control frame (3 × 1 × 2 m) was recorded by the 3 cameras then removed. Each of the participants had a 10 minute warm up and additional time to practice both of the walking scenarios. The participants were instructed to walk at a preferred speed and could begin anytime they felt comfortable. The aqua free walking and aqua walking with the aqua-noodles walking was randomly assigned. Each participant was asked to walk a distance of 5 m a total of 10 times, 5 with and 5 without the aqua-noodles. From these 10 trials 3 with and 3 without were digitized for data calculations.

4. Data processing and analysis

All the video data was recorded and imported into Kwon 3D for digitization of the joints and the kinematic variables were exported to Microsoft Excel 2010. The 3D coordinates are calculated through the Direct Linear Transformation method (Walton, 1981).

1) Control frame and joint points estimation

In order to set the coordinates of the real space, i.e. capture volume, the control point frame of 3 × 1 × 2 m set up before the subjects entered the swimming pool. The left and right direction (mediolateral) was set as the X axis, the vertical direction as the Z axis, and the Y axis as the cross product of X and Z axis vectors. Ten joint centers, left and right hip, knee, ankle and toe, were calculated for each subject during each of their trials.

2) Calculation of the 3D coordinates

Direct linear transformation method was applied to the manually digitized 2D data provided from the cameras. Prior to the recording of the video a control frame with 16 control points was placed in the capture volume. Through the known relationship between the 16 control points in the 3D and the digitized 2D coordinates in the video camera the 3D coordinates were extrapolated. Each of the extrapolated data points applied a cubic spline function for the interpolation of the digitized points. The 3 digital cameras all recorded full HD at 125 Hz and synchronized. The 3D coordinates were further processed using a Butterworth 2nd low-pass filter with a cut off frequency of 6 Hz to reduce any noise. Each of the low limb joint centers, i.e. the ankle and knee joint, used the midpoint method developed by Tylkowski-Andriacchi (Singhai et al., 2014) to estimate the corresponding joint center. Furthermore, each of the segments was given a local reference frame within the global reference frame.

3) Variable calculations

Each of the segments joint angles and positions were used to calculate the need variables.

(1) Defining gait phases

A total gait cycles was described as the point from the right heel contact (RHC) until the left toe-off (LTO). The left support phase was described as the left heel contact (LHC) to the left toe-off (LTO) and as the right heel contact (RHC) to the right toe-off (RTO) for the right support phase.

(2) Gait speed

The speed of the movement of each segment was divided into the 3 axis, X-axis, Y-axis, and Z-axis. The movement in the Medio-lateral plane was described by X-axis, and the movement in the vertical plane was described by X-axis. The summation of the segments in the X and Y direction were then calculated to give the speed (m/sec), for each of the frames recorded.

(3) Angle

From the coordinates of the joint centers and the connecting segments the ankle flexion and extension, knee flexion and extension, and hip flexion and extension were calculated.

(4) Step width

The distance from the left heel contact to the right heel

Table 2. Stance phase times walking with and without the aqua-noodles

	With aqua-noodles (s)	Without aqua-noodles (s)	*t*	*p*
Unaffected side	1.30±0.30	1.36±0.39	.529	.610
Affected side	1.82±0.54	1.47±0.27	-3.047	.014

Table 3. Maximum knee height walking with and without the aqua rods

	With aqua-noodles (m)	Without aqua-noodles (m)	*t*	*p*
Unaffected side	0.57±0.07	0.54±0.10	-.997	.345
Affected side	0.56±0.04	0.53±0.06	-2.364	.042

Table 4. Stride length for walking with and without the aqua rods

	With aqua-noodles (m)	Without aqua-noodles (m)	*t*	*p*
Unaffected side	0.70±0.18	0.84±0.20	3.325	.009
Affected side	0.83±0.14	0.88±0.15	1.447	.182

contact was calculated.

(5) Step time

The step for each of the legs corresponded from the heel contact to the toe off.

(6) Maximum knee height

The maximum knee height was calculated from the position of the knee's joint center in the vertical plane.

5. Statistical processing

SPSS (version 21.0 for windows) was used for all the statistical analysis including the calculation of the descriptive statistics providing the means and standard deviations for the 5 trials. A paired *t*-test was used to compare the differences between the gait trials using the aqua noodle during walking and without using the aqua noodle (control condition). A significance level of 0.05 was established to investigate if the differences were significant.

RESULTS

The results of the aqua gait with and without the aqua noodles are displayed for each of the important events as explained in the methods section.

1. Stance phase

Table 2 shows the stance phase times for the affected and unaffected sides for the two conditions walking with and without the aqua-noodles. The stance time is significantly longer for the affected side when using the aqua-noodles ($p < .05$).

2. Maximum knee height

Table 3 shows the maximum knee height (m) for the affected and unaffected sides for the two conditions walking with and without the aqua-noodles. There is no significant difference in the knee height for the unaffected side but is significantly increased for the affected side ($p < .05$).

3. Stride length

Table 4 shows the stride length (m) for the affected and unaffected sides for the two conditions walking with and without the aqua-rods. The stride length increased for both the affected and unaffected sides when walking without the aqua-rods but was only statistically significant for the unaffected side ($p < 0.05$).

Table 5. Knee Range of Motion for walking with and without the aqua rods

	With aqua-noodles (°)	Without aqua-noodles (°)	*t*	*p*
Unaffected side	50.39±27.01	54.75±27.16	.681	.076
Affected side	34.37±18.99	22.60±12.49	-2.001	.513

Table 6. Ankle Range of Motion for walking with and without the aqua rods

	With aqua-noodles (°)	Without aqua-noodles (°)	*t*	*p*
Unaffected side	20.09±10.68	21.57±7.23	.661	.525
Affected side	16.68±10.85	12.23±5.02	-.983	.351

Table 7. Maximum knee angular velocity for walking with and without the aqua rods

	With aqua-noodles (°/s)	Without aqua-noodles (°/s)	*t*	*p*
Unaffected side	91.51±45.35	91.81±34.72	-1.108	.297
Affected side	44.33±30.07	37.41±25.33	.026	.980

Table 8. Maximum ankle angular velocity for walking with and without the aqua rods

	With aqua-noodles (°/s)	Without aqua-noodles (°/s)	*t*	*p*
Unaffected side	42.48±26.90	33.90±33.72	-.734	.482
Affected side	28.28±10.71	27.31±18.79	-.166	.871

4. Knee ROM

Table 5 shows the maximum knee range of motion (°) for the affected and unaffected sides for the two conditions walking with and without the aqua-rods. There was no significant difference between conditions for the affected side however; there was a significant reduction in ROM of the knee for the unaffected side.

5. Ankle angle ROM

Table 6 shows the maximum ankle angle ROM for walking with and without aqua-noodles. The data shows no statistically significant differences between the ankle angle ROM.

6. Maximum knee angular velocity

Table 7 shows the angular velocity for the knee during walking with and without aqua-noodles. There were no significant differences for the affected and unaffected side.

7. Maximum ankle angular velocity

Table 8 shows the maximum ankle angular velocity for walking with and without aqua-noodles. There were no significant differences for both the affected and unaffected side.

DISCUSSION

The purpose of this study was to investigate the changes of gait while using aqua - noodles during underwater exercises in patients with hemiplegic patients. The results of this study showed that the use of aqua-noodles increased the time required for the affected side, increasing the maximum knee height on the affected side, and decreasing the stride length of the unaffected side. These results are consistent with the findings of Keneda et al. (2007) that deep water running improves the balance ability of the elderly and stability of the hip joint in the 3 conditions ground walking, underwater walking and deep water running in healthy subjects. In addition, in this study of underwater rehabilitation, stroke patients can easily move their limbs with less force due to buoyancy, which is also in line with Koury's (1996) study reporting an improvement of coordination for both upper and lower limbs.

Park et al. (2005) found that the underwater rehabilitation exercise had a positive effect on the chronic back pain, range of joint motion, hip extension, and flexor muscle strength. Park's (2005) study was on the effect of water rehabilitation before and after the exercise on the ground. This study suggests that systematic gait training is needed to identify changes in the use of aqua-noodles in the water. In addition, in the case of a treadmill walking study using a mountain climbing poles, it was found that the stride pendulum was increased when a mountain climbing poles were used for walking on the ground (2007). In addition, it was reported that the elderly over 65 years old gait patterns were positively affected and they had a longer stride length when using the walking aids (Yun, 2007). The different results reported in previous studies show are a result of the difference in function of the walking aids on the ground and the walking aids in the water. In the case of walking aids on the ground, it makes mobility easier as it helps stability during walking and the spreads the pushing power by the increased contact surfaces with the ground. However, in the case of the walking aids in the water, because the noodle and the body has natural buoyancy and provides support, it helps in the upward movement rather than horizontal movement.

In a study by Kim et al. (2006) on the effect of the underwater rehabilitation exercise program on the walking characteristics of stroke patients, they reported that the knee's range of motion increased significantly as a result of underwater exercise for 12 weeks. However, in this study, there was no statistically significant difference. However, the use of aqua-noodles showed a tendency to increase ROM of the affected knee and ankle, which is due to the increase in strength due to the aquatic exercise. This increase in ROM of the affected knee and ankle is thought to be because of the increased stability of the participant helping them feel more comfortable and able to use more joint ROM.

CONCLUSION

The purpose of this study is to verify the effectiveness of underwater walking exercises in hemiplegic patients and to suggest a more appropriate walking exercise environment. Hemiplegic patients were instructed to walk in a pool depth of 1.3 m (approximately chest height) and kinematic data was collected for their affected and unaffected legs. The following variables were recorded and calculated; stance phase time (sec), maximum knee joint height (m), knee ROM (°), ankle joint ROM (°), maximum knee angular velocity (°/s), and maximum ankle angular velocity (°/s). First, the stance phase time (sec) and maximum knee height (m) increased for the affected and unaffected side. This was considered to be a result of ease of vertical movement due to the buoyancy of the aqua-noodle.

Second, the use of aqua-noodles seems to improve the knee and ankle ROM of the affected lower limbs. Although there was no statistically significant difference in this study, the use of aqua noodles tended to increase the ROM of the knee joint by 12°, which is expected to increase the effect of aquatic exercise.

In order to provide ideal walking practice conditions in water, it is necessary to scientifically provide data to verify the effects of using aids during aqua walking practice. However, due to the limitations of the movement in the water, there is a vast dearth of research dealing with the motion capture during aqua walking. Based on the results of this study, it is expected that aqua walking coupled with additional aquatic exercises, may provide a diversity of exercise methods for rehabilitation of patients and the elderly. This study provides useful insights into the effect of using aqua-noodles may have on walking coordination and how it they can be used to provide stability and increase movement range of motion.

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