KINEMATIC ANALYSIS OF THE MOVEMENT PATTERNS OF STROKE PATIENTS USING AN AQUA-REHABILITATION PROGRAM

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This study analyzed the effect of a BK Aquatic Protocol (aqua-rehabilitation program) on the gait patterns of stroke patients. Seven subjects were divided into three stages on the basis of initial assessment of motor ability. The program varied on the basis of motor ability group. The subjects exercised three times a week for 12 weeks. Each exercise bout lasted 50 minutes. The BK Aquatic Protocol (as the motor skills improved, the graded exercise program appropriately changed) was followed. Four digital camcorders were used to obtain the kinematics of the patients' gait before and after participation in the aqua-rehabilitation program. Several positive kinematic changes occurred in the gait patterns of the stroke patients from pre- to post test in association with the intervention of the aqua-rehabilitation program.

KEY WORDS: aqua-rehabilitation exercise, gait pattern, stroke

INTRODUCTION: As human longevity has increased, there has been an accompanying increase in the incidence of stroke (Lindsay & Bone, 2004). Often these strokes have an adverse influence on the ability to perform daily living activities (e.g., gait patterns) of those affected and subsequently reduce the quality of their lives. Aqua-exercise has been shown to increase muscle strength and improve motor ability in patients with brain dysfunction (O'Connor, Lox, & Rees, 2004). Also, aqua-exercise provides a good modality because of the reduced loads associated with exercising in water. Thus, it provides an opportunity for earlier rehabilitation intervention in patients with weakened muscular systems. Therefore, the purpose of this study was to analyze the effect of an aqua-rehabilitation program on the gait patterns of stroke patients and to possibly develop guidelines for others to apply in similar programs for stroke patients.

METHODS:

Subjects: Seven male patients participated voluntarily in this study (means and SDs for height, age, weight, and disability level (according to Korean law on persons with disabilities) were 170 $\pm$ 5.45 cm, 57 $\pm$ 5 years, 69 $\pm$ 6.1 kg, and 2.14 $\pm$ 0.69, respectively). At the beginning of the study all subjects could walk at least with walker or cane and received medical approval to participate in the aqua-rehabilitation program.

BK Aquatic Protocol: Byung-Kuk Chung (or BK) Aquatic Protocol was applied to this study. This programs is divided by three stages: Stage 1 - Relaxation and Elongation, Stage 2 – NPRM (Normal Posture Reaction Mechanism) and Neuromuscular Facilitation, and Stage 3 - Gait Circuit Training. All exercise stages of the BK Aquatic Protocol are performed in water. The volunteer stroke patients, who participated in the current study, exercised three times per week for 12 weeks. Each exercise bout lasted 50 minutes. Volunteers were assigned to stages on the basis of their motor ability and progressed from one stage to another as they developed.

Data Collection and Kinematic Analysis: Three dimensional analysis was performed using the Kwon3D system (Visol., Inc., Seoul, Korea). Four digital cameras, operating at 60 HZ, were used to collect kinematic data. The body model that was implemented was based on point modeling of the 24 reflective markers. To get the center of mass of the shank and thigh, the ankle and knee joints were defined through the midpoint method and the hip defined through Tylkowski (1982) method through the identification of the right anterior superior iliac spine (ASIS), left ASIS, sacrum and inter ASIS distance (Kwon, 2003). Stride length was measured as the horizontal displacement from paralyzed foot heel contact with the ground to the next consecutive paralyzed foot heel contact with the ground. Ankle, knee, and hip angles were measured from the dot product of two vectors. Toe out angle was defined as the angle formed by a line in the anterior-posterior direction of movement and a line connecting the heel to the toe in the plane of the floor (X-Y plane). Trunk lean was defined in the Y-Z plane from the center of both hip joints to the center of the both shoulder joints relative to the vertical. Video tape of each subject's natural gait pattern was collected before the aqua-rehabilitation program started and after 12 weeks of exercise. Paired sample t-tests were performed to analyze differences between pre- and post tests ($p < .05$).

RESULTS AND DISSCUSSION:

Displacements and Velocities: Table 1 shows pre- and post test kinematic variables for subjects investigated in this study. Based on the data, there was a significant increase of 0.14 m/s in the mean velocities of the whole body centers of mass. This result is in accord with a similar study by Teixeira-Salmela, Nadeau, & Olney (2001). The stride length and stride length/length of lower extremity were significantly increased from pre-test to post test. Several previous similar studies supported these results. In comparison to patients with Downs syndrome, the subjects in the current study did not show as great an improvement in stride length following an aqua-rehabilitation program. This implies that stroke patients may need a longer aqua-rehabilitation program to achieve desired stride length improvements in comparison to other patient groups. Typically, it would be desirable to reduce the vertical displacement of the center of mass of the body in gait patterns because of the potential for wasted energy. However, the stroke patients in this study, prior to the exercise intervention, exhibited little lower extremity extension. Thus, the vertical displacements of their centers of gravity were substantially less than the 10 cm that is expected in a normal adult population (Inman, Ralston, & Todd, 1988). From pre- to post test the subjects exhibited greater use of their lower extremities as seen in Table 1. Thus, the patients were able to exert greater energy output to facilitate their walking patterns, likely as a result of increased muscular strength of their lower extremities.

Table 1: Kinematic Results of the Gait Patterns from Pre- to Post Test

Parameters	Pre-test (Mean±SD)	Post Test (Mean±SD)
Velocity of whole body center of mass (m/s)*	0.56±0.14	0.70±0.19
Stride length(cm)*	73.44±12.65	88.20±17.50
Stride length/length of lower extremity*	0.82±0.15	0.99±0.20
Vertical displacement of the center of mass (cm)*	5.24±1.94	6.82±1.76

*Significant difference ($p < .05$).

Orientations of Segments and Joints: All orientations of segments and joints for pre- and post test shown in Table 2 were obtained from the second heel contact (SHC) of the affected side of the patients for the stride analyzed. The trunk lean angle significantly decreased 3.34º from pre- to post test, more closely approximating normal orientation of the trunk at heel contact. The rotation angle of hip was shown to be 4.72º±2.38º and 9.35º±4.09º for pre-test and post test, respectively. This finding agrees with the study by Houghlum (2001), who suggested that increased rotation of the hips helps to increase the stride length as was found in the current study. The toe out and ankle angle were significantly different between pre- and post test. Toe out angle changed from 11.87º±8.78º to 22.77º±9.42º and ankle angle changed from 93.88º±6.23º to 105.74º±10.75º. Generally, normal people have 7–8º of the toe out angle at heel contact (HC), whereas, the stroke patients had a much greater angle, and this angle increased in spite of the aqua-rehabilitation program. Similarly, the ankle joint angle in normal people is expected to be less than what was obtained in the stroke patients. Observation of the stroke patients' movement pattern revealed an external rotation of the lower extremity which increased from pre- to post test, likely the result of increased ability to more forcefully activate the hip joint flexors and outward rotators as a result of increased strength. This may have precipitated the undesirable changes in the foot toe out position and plantar flexion of the ankle joint at SHC. Thus, in addition to the increase in strength, it appears that the stroke patients need additional motor skill training to compensate for this increased strength.

Table 2: Orientations of Segments and Joints at SHC from Pre- and Post Test

Parameters	Pre-test (Mean ± SD)	Post Test (Mean± SD)
Trunk lean angle (°)*	8.67±3.32	5.33±4.73
Rotation angle of hip(°)*	4.72±2.38	9.35±4.09
Flexion of hip(°)	140.33±9.59	137.95±11.10
Knee joint angle (°)	169.15±6.45	167.64±11.74
Ankle joint angle (°)*	93.88±6.23	105.74±10.75
Toe out angle (°)*	11.87±8.78	22.77±9.42

*Significant difference ($p < .05$).

Angular Velocity: Table 3 shows the maximum angular velocity of the hip, knee, and ankle joint of the affected lower extremity during gait from pre-test to post test. There was only a significant increase in the angular velocity for the knee joint. However, the other joints showed a similar trend from pre- to post test. Typically, maximum angular velocities of these three joints occurred after the subjects moved from a somewhat unstable support on their affected side to a more stable support on their non-affected side (see Figure 1). These data imply that an increase in muscle strength in the affected extremity resulted in an increase in angular velocity of the segments and joints of these limbs.

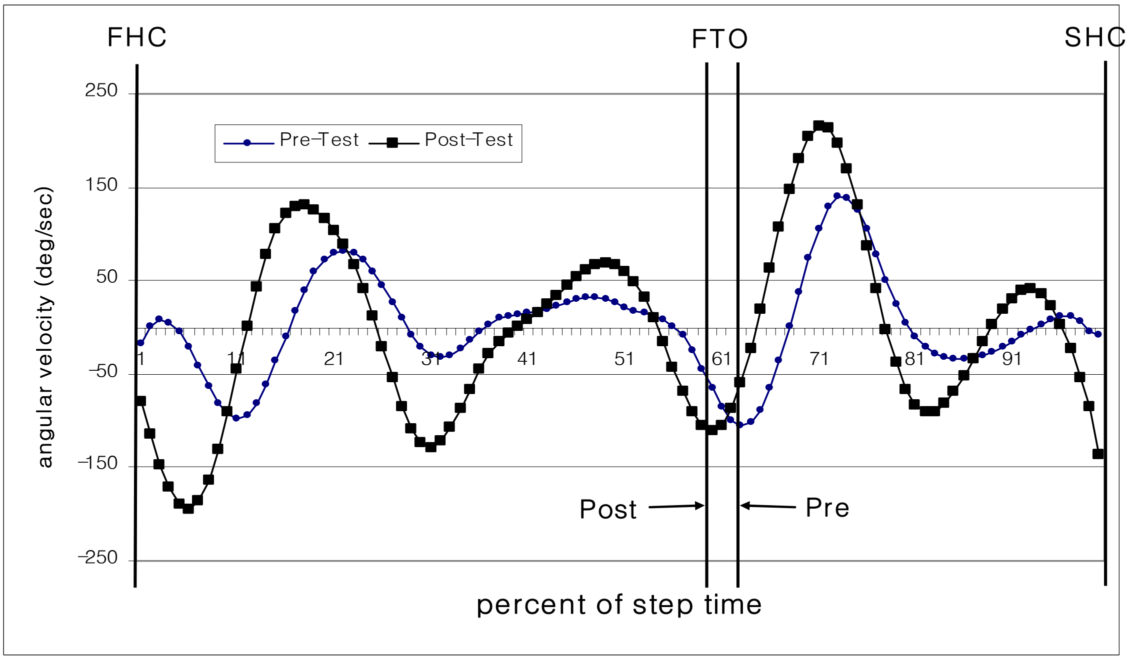

Figure 1: Knee Angular Velocity of Affected Lower Extremity during Gait from Pre- to Post Test of Typical Subject Normalized to 100 Percent Step Time (FHC – first heel contact with affected foot, FTO –toe off of affected foot, SHC – second heel contact of affected foot)

Table 3: Maximum Angular Velocity of Affected Lower Extremity during Gait from Pre- to Post Test

Parameters	Pre-test (Mean ± SD)	Post test (Mean± SD)
Hip(º/s)	92.78±18.20	124.19±36.34
Knee(º/s)*	91.29±67.25	159.86±90.15
Ankle(º/s)	168.94±58.64	207.63±96.96

*Significant difference ($p < .05$).

CONCLUSION: The major findings of this study incorporating an aqua-rehabilitation program with stroke patients were that these individuals had significant positive changes in their walking gait. This was evident in increased patient selected walking speed, stride length, pelvic rotation, vertical displacement of the center of mass, maximum angular velocity of the knee joint, and hip rotation; and in decreased trunk lean. On the other hand, negative significant changes occurred at heel contact in increased toeing out and increased ankle plantar flexion. These negative changes were likely the result increases in muscular strength of the stroke patients who were able to more forcefully move their affected leg. It is hypothesized that additional motor training is needed following the aqua-rehabilitation program to assist the stroke patients to control their greater strength and to ultimately move their lower extremities in patterns more closely resembling the walking patterns of individuals who have not had brain damage. In general, the aqua-rehabilitation program is recommended as a method to improve several aspects of the walking pattern of stroke patients and to help them regain strength in their affected lower extremity. This program should be combined with a motor skill program to help the patients appropriately use their increased strength in assimilating normal walking gait.

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