Effects of ankle joint mobilization with movement and weight-bearing exercise on knee strength, ankle range of motion, and gait velocity in patients with stroke: a pilot study

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Abstract. [Purpose] The purpose of this study was to investigate the effects of ankle joint mobilization with movement on knee strength, ankle range of motion, and gait velocity, compared with weight-bearing exercise in stroke patients. [Subjects and Methods] Thirty subjects with chronic stroke were divided into three groups: MWM (n = 12), WBE (n = 8), and control (n = 10). All groups attended physical therapy sessions 3 times a week for 5 weeks. Subjects in the MWM group performed mobilization with movement exercises, whilst participants in the WBE group performed weight-bearing exercises. Knee peak torque, ankle range of motion, and spatiotemporal gait parameters were evaluated before and after the interventions. [Results] Knee extensor peak torque increased significantly in both MWM and WBE groups. However, only the MWM group showed significant improvement in passive and active ankle range of motion and gait velocity, among the three groups. [Conclusion] Ankle joint mobilization with movement intervention is more effective than simple weight-bearing intervention in improving gait speed in stroke patients with limited ankle motion.

Key words: Mobilization with movement, Stroke, Weight-bearing exercise

INTRODUCTION

Recovery of gait function is a primary rehabilitation goal, with the majority of stroke patients suffering from a reduction in gait velocity1). Independent gait is a crucial factor in carrying out activities of daily living following stroke. According to previous studies on stroke patients, sensorimotor dysfunction causes limited joint range of motion (ROM) and muscle weakness in the lower extremities of the affected side, leading to difficulties in performing functional activities such as sit-to-stand and gait2–4). Limited ankle joint motion directly and negatively affects functional ability5). The primary causes of limited ankle joint motion include plantarflexor spasticity and dorsiflexor weakness. Long-term limited motion, resulting from a primary cause, alters the mechanical properties of the ankle muscles and connective tissues, bringing about motion deterioration. This is considered the secondary cause of limited ankle joint motion3–5).

Appropriate ankle motion and proper muscle contraction are required for functional gait, as they facilitate the maintenance of stability and efficiency during gait3). In stroke patients, limited motion of the ankle on the affected side decreases the individual’s ability to shift the center of mass (COM), resulting in instability during gait3). In a recent study, joint mobilization techniques applied to limited-motion ankle joints in stroke patients were found to be effective in improving ROM5). However, joint mobilization techniques focused on improving passive ROM (PROM) only, and functional gait requires both...
active ROM (AROM) and PROM. Therefore, an intervention aimed at improving AROM is required in addition to joint mobilization techniques.

Mulligan first proposed mobilization with movement (MWM) as a joint mobilization technique\(^6\). This intervention proved effective for the improvement of dorsiflexion motion in healthy adults\(^7\). Ankle MWM can be applied in both weight-bearing and non-weight-bearing positions, with the weight-bearing position being more effective for improving ankle ROM\(^8\). Weight-bearing MWM allows the individual to weight-bear on the affected side, which is necessary for hemiplegic patients after stroke, and is expected to improve muscle strength, ankle ROM, and the ability to shift the COM using the lower extremities of the affected side. However, studies showing that weight-bearing MWM helps stroke patients improve their functional abilities are rare.

In the current study, the effects of ankle MWM on knee strength, ankle ROM, and gait velocity were investigated in stroke patients. Analyses were also conducted to determine whether changes observed following intervention in a weight-bearing position were the result of weight-bearing on the affected side, or the effect of MWM combined with weight-bearing and joint mobilization. Weight-bearing exercise (WBE) was defined as the weight-bearing intervention in the MWM position without joint mobilization.

**SUBJECTS AND METHODS**

**Subjects**

Subjects were recruited from the National University Hospital in Korea. All of the subjects read and signed an informed consent form, approved by the institutional review board of Jeonju University (JIIRB2013001) and in accordance with the Declaration of Helsinki. This study was a randomized, controlled trial, with three groups. A total of 38 stroke patients participated in this study, including 13 subjects in the MWM group, 12 in the WBE group, and 13 in the control group. Inclusion criteria included: the presence of hemiplegia confirmed by physical examination; ability to walk without an assistive device for more than 10 m; and limited dorsiflexion PROM with contracture on the hemiplegic ankle. Participants were excluded from the study if they: presented contraindications for joint mobilization (i.e., ankle joint hypermobility, trauma, or inflammation); had language or cognitive deficits that would impair their ability to provide informed consent; or were concurrently receiving similar interventions outside of this study.

**Methods**

MWM was conducted on the talocrural joint, as described by Mulligan\(^6\). The subject placed the unaffected leg on the floor and the hemiplegic leg on a stool (height: 30 cm), with the back of the subject’s distal tibia and the pelvis of the therapist wrapped using a non-elastic treatment belt. The subjects actively maintained dorsiflexion with forward shifting of the center of mass (COM); at the same time, the therapist performed an anterior glide on the tibia using the belt. For effective gliding, the talus and forefoot were fixed by the therapist using the web space of the hand closest to the anterior joint line. A grade III glide was sustained for 10 seconds during slow active dorsiflexion to the end of the pain-free range; the treatment belt was kept perpendicular to the long axis of the tibia throughout the movement, and released after returning to the start position. Six sets of 10 repetitions were performed, with a 1-minute break between sets\(^9\). If the participant felt pain during the treatment, the participant was excluded from the study immediately. In the WBE intervention, the lower extremity on the affected side was placed on a stool while standing, with the subject asked to actively bend his/her knees to shift the COM to the lower extremity on the affected side. The therapist’s hand was positioned in the same place as in the MWM technique, but without the therapist-guided gliding with a belt. Traditional physical therapy was performed with all participants, 3 times a week for 5 weeks. Patients in the MWM and WBE groups received an additional 30 minutes of MWM or WBE, including warm-up and cool-down for 5 minutes using a stationary bicycle, 3 times a week for 5 weeks, giving a total of 15 treatment sessions.

Maximal concentric contraction of knee extensors and flexors was measured with an isokinetic dynamometer (System 3 Pro; Bio-dex Medical Systems, Shirley, NY, USA). The subject was seated with the knee joint axis aligned with the mechanical axis of the dynamometer, and after a few practice trials, the subjects was instructed to push and pull the attachment as hard and as fast as possible. Five maximum concentric contractions were performed at 60°/s\(^9\), with the peak torque generated over 5 repetitions recorded and normalized to body weight (Nm/kg). To measure passive ROM of the ankle, the subject was seated in the chair of the isokinetic dynamometer with the foot pressed firmly against a foot plate attached to the dynamometer and the knee flexed at 30°. Prior to measurement, the subject’s feet and the corresponding footplates were fixed firmly using a Velcro strap; measurements were taken passively from maximal plantarflexion to maximal dorsiflexion. Maximal plantarflexion was defined as the maximum angle before the foot lifted from the surface of the foot plate, while maximal dorsiflexion was defined as the maximum angle before the heel lifted off the surface of the foot plate\(^10\). The ankle active ROM test measured the range of active motion from plantarflexion to dorsiflexion.

Spatiotemporal gait parameters were measured using a GAITRite mat (CIR Systems, Clifton, NJ, USA). The mat is 366 cm long and 81 cm wide, containing a grid with 48 by 288 sensors (13,824 total sensors) arranged 1.27 cm apart. Data were sampled at 30 Hz. The participants performed three trials, during which they walked at their preferred speed, without any gait-assistance device, across a level 10 m walkway with a pressure-sensitive mat in the middle. Before the data col-
lection began, the subjects performed one practice walking trial to familiarize themselves with the procedure. Velocity and step length were the primary variables obtained. Three trials were recorded for each participant and the average used for subsequent analysis.

The data were analyzed statistically using SPSS 18.0 software (SPSS, Chicago, IL, USA). General characteristics prior to the interventions were analyzed via descriptive statistics, with knee strength, ankle ROM, and gait parameters analyzed using one-way analysis of variance (ANOVA). Differences within groups following interventions were analyzed with paired t-tests, while differences between groups were analyzed using one-way ANOVA and Tukey’s post hoc multiple-comparison test. Statistical significance α was set at 0.05.

RESULTS

Eight subjects dropped out during the study: 1 subject in the MWM group, who moved away; 4 subjects in the WBE group (2 were hospitalized and 2 withdrew for personal reasons); and 3 subjects in the control group (1 due to employment and 2 due to other health problems). Thus, a total of 30 subjects, 12 in the MWM group, 8 in the WBE group, and 10 in the control group were analyzed. No significant differences in baseline characteristics or physical parameters, prior to intervention, were observed among the three groups (Table 1).

Knee extensor peak torque values following intervention increased 20.7% in the MWM group, 14.9% in the WBE group, and 1.6% in the control group. Intragroup statistical analysis revealed a significant increase in the MWM and WBE groups after intervention, when compared to pre-intervention (p < 0.05). Statistical analysis between groups showed significant increases in peak torque values of knee extension in the MWM and WBE groups (p < 0.05) compared to the control group. Peak torque values of knee flexion increased 24.8% in the MWM group, 15.4% in the WBE group, and 7.7% in the control group. Intragroup statistical analysis showed a significant difference in the MWM and WBE groups (p < 0.05), however, there was no significant difference between groups (Table 2).

There was a 4.7° increase in ankle joint PROM after intervention in the MWM group, compared to 2.1° and 0.6° in the WBE and control groups, respectively. Intragroup statistical analysis showed significant differences for the MWM and WBE groups (p < 0.05), whilst statistical analysis of differences between groups revealed a significant increase in the MWM group compared to the control group (p < 0.05). AROM increased 6.1° in the MWM group, 1.4° in the WBE group, and 0.1° in the control group. Intrarogroup statistical analysis showed a significant difference in only the MWM group (p < 0.05). Analysis of the differences between groups revealed a significant increase in the MWM group compared to the control and WBE groups (p < 0.05) (Table 2).

Gait velocity increased 0.08 m/s after intervention in the MWM group, 0.05 m/s in the WBE group, and 0.01 m/s in the control group. Intragroup statistical analysis showed significant differences in the MWM and WBE groups (p < 0.05). Statistical analysis of the differences between groups revealed significant improvement in the MWM group compared to the control group (p < 0.05). Step length on the affected side increased 3.0 cm, 2.6 cm, and 0 cm in the MWM, WBE, and control groups, respectively. Intragroup statistical analysis revealed significant differences in the MWM and WBE groups (p < 0.05). Analysis between groups showed a significant increase in the MWM group, compared to the control group (p < 0.05). Step length on the unaffected side increased 4.1 cm in the MWM group, 0.6 cm in the WBE group, and 0.5 cm in the control group. Intragroup statistical analysis showed a significant difference in only the MWM group (p < 0.05). Analysis of differences between groups revealed a significant increase in the MWM group compared to the WBE and control groups (p < 0.05) (Table 2).

DISCUSSION

Appropriate gait is an essential factor for independent living and social participation. However, gait velocity in stroke patients is approximately half that of healthy individuals of the same age. In general, proper ankle joint motion plays a critical role in functional ability, including gait31. However, the ankle joints of stroke patients typically exhibit limited motion, leading to impaired gait performance31. A previous study suggested that it is necessary to improve ankle motion and strengthen muscles to recover gait ability31. In order to achieve those goals, MWM and WBE interventions were applied to stroke patients with an average gait velocity of 0.6 m/s in this study. The results showed a significant increase in knee extension strength in both MWM and WBE groups, as well as significant increases in ankle ROM and gait velocity in the MWM group.

In the present study, significant improvements in knee extension peak torque were observed in the MWM (13.4 Nm) and WBE (9.0 Nm) groups. A previous study of stroke patients by Flansbjer et al.11) reported that peak torque of the affected side improved by 13.7 Nm in knee extension, when muscle strength exercises were performed using an isokinetic device, twice a week for ten weeks. Jönhagen et al.12) observed that single-leg lunges result in muscle contraction of the quadriceps; eccentric contraction of the quadriceps occurs when shifting the COM forward, isometric contraction occurs when retaining the posture following a forward shift, and concentric contraction occurs when shifting the COM to the original position. Moreover, a study by Shields et al.13) demonstrated that single-leg squat exercises improved quadriceps muscle strength.

It was also shown in the present study that repeated muscle contraction of knee extensors while shifting the COM to the lower extremity on the affected side was effective for enhancing knee extensor strength in both the MWM and WBE
interventions. However, peak torque differences were higher in the MWM group than in the WBE group, due to forward gliding of the tibia performed by a therapist with a belt, performed simultaneously with MWM exercises. This maneuver increased the forward shifting of the COM and increased knee flexion and dorsiflexion, resulting in strength improvements in knee extension.

According to a previous study, an MWM intervention approach combining a relative anterior glide of the tibia on the talus with active dorsiflexion movements is effective for improving dorsiflexion. In particular, ankle ROM improvement is more prominent when MWM is performed in a weight-bearing position than in a non-weight-bearing position. In this study, PROM (4.7°) and AROM (6.1°) increased significantly in the MWM group, when compared to the other two groups. MWM induced recovery of accessory movement in the joints after therapists performed a forward gliding of the tibia, accompanied by a shift in the COM, resulting in improved joint ROM. This finding indicates that WBE results in limited improvements in ankle ROM mediated by stretch in the plantarflexors. Therefore, gliding should be performed for a given joint to aid in effective motion improvement.

Of particular note was the improved AROM in the MWM group. The reason for this result is considered to be the forward gliding of the tibia by the therapist with a belt, performed simultaneously with MWM exercises, causing a forward shifting in the COM and increased contraction of the dorsiflexors and plantarflexors.

Gait in stroke patients is characterized by a simultaneous decrease in step length and velocity. In the present study, a significant increase in gait velocity was observed in the MWM group, compared to that in the other two groups. Further, the step lengths of both the affected and unaffected sides increased only in the MWM group. The step length of the bilateral lower extremities increased in the MWM group due to an increase in muscle strength of the lower extremities, and the improved ankle ROM, compared to the other two groups.

Many researchers have shown that the strength of affected knee extensors and ankle plantarflexors correlates

| Table 1. Characteristics of participants at baseline |
|-----------------------------------------|-----------|-----------|
| Variables                      | MWM (n = 12) | WBE (n = 8) | Control (n = 10) |
| Age (years)                  | 48.3 ± 11.5 | 50.5 ± 9.9 | 47.4 ± 10.7 |
| Gender (M/F)                 | 9/3        | 6/2        | 9/1        |
| Hemiplegic side (R/L)        | 5/7        | 5/3        | 6/4        |
| Type of stroke (ischemia/hemorrhage) | 5/7        | 3/5        | 5/5        |
| Disease duration (months)    | 60.0 ± 36.6 | 50.6 ± 34.6 | 62.7 ± 41.0 |
| Height (cm)                  | 167.3 ± 8.0 | 165.1 ± 4.9 | 171.4 ± 6.4 |
| Weight (kg)                  | 63.3 ± 6.5  | 62.6 ± 4.2  | 67.9 ± 6.6  |
| K-MBI                         | 85.3 ± 3.6  | 84.1 ± 5.5  | 83.3 ± 6.6  |
| MMAS(0/1/2/3/4)              | 0/5/6/1/0   | 0/3/5/2/1   | 0/3/4/1/0   |

Values are expressed as mean ± SD or frequency.
MWM: Mobilization with movement; WBE: Weight-bearing exercise; K-MBI: Korea-modified Barthel index; MMAS: Modified Modified Ashworth Scale

| Table 2. Effect of intervention in each group |
|---------------------------------------------|-----------|-----------|
| Parameters                  | MWM group | WBE group | Control group |
|                             | Before | After | Before | After | Before | After |
| Knee strength\*             | Extensor | 70.7 ± 47.2 | 91.4 ± 50.8\* | 76.8 ± 40.3 | 91.7 ± 42.5\* | 79.0 ± 42.9 | 80.6 ± 42.8 |
|                            | Flexor  | 13.8 ± 9.4  | 38.6 ± 29.4\* | 15.0 ± 14.6 | 30.4 ± 27.7\* | 14.3 ± 10.6 | 22.0 ± 16.4 |
| Ankle ROM (°)               | Passive | 62.9 ± 7.7  | 67.6 ± 6.3\* | 61.4 ± 8.6  | 63.5 ± 7.5\* | 57.4 ± 7.4  | 58.0 ± 6.8  |
|                            | Active  | 29.5 ± 7.9  | 35.6 ± 7.2\* | 36.2 ± 12.3 | 37.6 ± 13.1 | 33.5 ± 15.0 | 33.6 ± 14.0 |
| Gait velocity (m/s)         | 0.55 ± 0.19 | 0.63 ± 0.20\* | 0.61 ± 0.13 | 0.66 ± 0.15\* | 0.52 ± 0.12 | 0.53 ± 0.11 |
| Step length (cm)            | Affected | 42.5 ± 8.4  | 45.5 ± 9.1\* | 42.5 ± 8.5  | 45.1 ± 9.5\* | 42.3 ± 5.6  | 42.3 ± 4.2  |
|                            | Unaffected | 35.0 ± 10.4 | 39.1 ± 10.4\* | 38.8 ± 4.3  | 39.4 ± 5.5  | 30.7 ± 8.5  | 31.2 ± 8.4  |

Values are expressed as mean ± SD.
\*Knee strength = peak torque ÷ body weight × 100.
\*p < 0.05 = significant difference between pre- and post-intervention within the group.
\*p < 0.05 = significant difference between WBE and control group.
with gait velocity in patients with stroke. After MWM intervention, improvement in strength of the knee extensors in the lower extremity of the affected side led to stronger concentric contraction, thereby contributing to stance stability. Accordingly, during gait, smooth shifting of the COM by the lower extremity on the affected side leads to increased step length in the lower extremity on the unaffected side\(^{14}\). Plantarflexors aid in shifting the COM toward the opposite lower extremity during late mid-stance throughout gait. Further, plantarflexors are responsible for generating a ground reaction force in the pre-swing phase, and contributing to swing initiation of the lower extremity, which improves the swing motion and facilitates increased step length\(^{17}\). Based on the aforementioned factors, the step lengths of both the affected and unaffected sides are believed to increase simultaneously.

In normal gait, a minimum of 10° of dorsiflexion is required for smooth anterior motion of the tibia on the talus during the stance phase. This movement plays a major role in absorbing body weight, as well as in forward propulsion of the body\(^{18, 19}\). In stroke patients, however, limited ankle dorsiflexion impairs the heel strike, which results in earlier time-to-heel-off, increased pronation, or increased knee hyperextension. These compensatory mechanisms restrict the shifting of the COM to the affected side and result in asymmetry, decreased gait velocity, and greater levels of energy consumption\(^{2, 20}\). In this study, the use of MWM resulted in increased ankle ROM, with this increase in motion contributing to improved step length and gait velocity on the unaffected side via smooth shifting of the COM following mid-stance during gait. However, ankle ROM was evaluated without separating dorsiflexion from plantarflexion; therefore, it is difficult to determine whether the increased ankle motion was due to increased dorsiflexion or plantarflexion.

The WBE group, which carried out a weight-bearing exercise similar to that of the MWM group, showed increased intragroup gait velocity after the intervention. However, this increase was lower than that of the MWM group. Similarly, the WBE group showed improved strength in knee extension, achieved through repeated COM shift training in the lower extremity of the affected side, but this improvement was modest compared to the change in the MWM group. Moreover, the lack of improvement in AROM and PROM on the affected side meant that no effect on gait velocity was observed.

This study has several limitations. First, including a non-standard wooden stool, and second, the small number of participants, make it difficult to generalize the statistical results. Further, ankle joint ROM was not classified by dorsiflexion and plantarflexion.

In conclusion, both the MWM and WBE interventions were effective for increasing knee extensor strength in stroke patients with limited range of ankle motion. However, the MWM intervention was more effective than the WBE intervention (i.e., simple weight-bearing without joint mobilization) in improving ankle ROM and gait velocity. Further research is needed to investigate the effect of treadmill training combined with ankle MWM in stroke patients.

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