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Original Article

Impact of the difference in the plantar flexor strength of the ankle joint in the affected side among hemiplegic patients on the plantar pressure and walking asymmetry

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Abstract. [Purpose] This study was to examine the changes in the gait lines and plantar pressures in static and dynamic circumstances, according to the differences in the strengths of the plantar flexors in the ankle joints on the affected sides of hemiplegic patients, and to determine their impacts on walking symmetry. [Subjects and Methods] A total of thirty hospitalized stroke patients suffering from hemiplegia were selected in this study. The subjects had ankylosing patterns in the ankle joints of the affected sides. Fifteen of the patients had plantar flexor manual muscle testing scores between poor and fair, while fifteen of the patients had zero and trace. [Results] The contact pattern of the plantar surface with the ground is a reliable method for walking analysis, which is an important index for understanding the ankle mechanism and the relationship between the plantar surface and the ground. [Conclusion] The functional improvement of patients with stroke could be supported through a verification of the analysis methods of the therapy strategy and walking pattern.

Key words: Hemiplegia, Plantar pressure, Walking asymmetry

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INTRODUCTION

More than 85% of patients suffering from stroke induced hemiplegia resume walking, with or without walking aids[1)]. Factors that can cause walking defects among patients after a stroke include the weakening of muscles, abnormal muscle activity, improper muscle coordination, defects in sense and vision, diminished length extension due to stiffness of the soft tissue, and the lack of a central program for muscle activity[2)].

Hemiplegic patients have certain walking characteristics due to malfunctions in coordination, which include a shorter step, longer stance phase, and shorter swing phase of the affected side, when compared to the unaffected side. Improvement in the walking ability of a hemiplegic patient can actually be checked by examining the improvement in walking symmetry, but this is still controversial[3)].

Proper control of the ankle joint is very important for a normal walking pattern. The activity of the plantar flexors of the ankle joint during the push-off stage of walking is a necessary factor that creates the driving energy for the forward movement of the lower limbs[4)]. Inefficient plantar flexor strength, which decreases the gait speed while walking, is a commonly observed phenomenon among hemiplegic patients[5)].

It is understood that the ground reaction force (GRF) of the lower limb has great influence on the correlation of the motor control of the lower limb, gait speed, and motor recovery among hemiplegic patients. Most hemiplegic patients exhibit talipes equinovarus when standing on two feet or walking, due to the lack of motor control and the ankylosing pattern of the

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gastrocnemius and soleus[6]. Moreover, they show an increase in the muscle support of the lateral plantar flexor, and decrease in push-off during walking. Weakened muscle strength, decreased motor and sensory function, an ankylosing pattern, and a lack of balance are all factors that can change the normal walking pattern of hemiplegic patients[7].

Many previous studies have described how physiotherapy can measure, evaluate, and manage the plantar pressure of hemiplegic patients that have injuries to the musculoskeletal, integumentary, and nervous systems[8], in which the control of the ankle joint while walking is strongly emphasized.

However, the relationship between malfunctions in ankle joint control and the walking pattern of hemiplegic patients is not yet clear. Moreover, many previous studies do not clearly explain the defects in ankle joint control and walking symmetry. Although there have been a number of studies regarding the ankylosing walking patterns of patients after strokes, the correlation between the gait speed and ankylosing pattern has not been sufficiently explained. This is because the ankylosing pattern is usually evaluated in a static situation, rather than a dynamic situation[9]. The walking analysis of a hemiplegic patient can become a therapy guideline for his/her functional recovery, while the analysis results can represent the level of functional recovery[10].

The purpose of this study was to examine the changes in the gait lines and plantar pressures in static and dynamic circumstances, according to the differences in the strengths of the plantar flexors in the ankle joints on the affected sides of hemiplegic patients, and to determine their impacts on walking symmetry.

SUBJECTS AND METHODS

The present study was conducted observing the research ethics described in Declaration of Helsinki and the research ethics regulations of the hospital. Sufficient explanations were provided to all the study subjects, who gave their written consent before participating in the study. A total of thirty hospitalized stroke patients suffering from hemiplegia were selected as research subjects in this study. The subjects had ankylosing patterns in the ankle joints of the affected sides, and MAS (Modified Ashworth Scale) scores of less than one. Fifteen of the patients had plantar flexor manual muscle testing (MMT) scores between poor and fair, while fifteen of the patients had ankylosing patterns in the ankle joints of the affected sides, and MASs of less than one. In addition, the latter group had plantar flexor muscle MMTs between zero and trace. All of the patients suffered from hemiplegia due to stroke, and were receiving traditional rehabilitation therapy after the stroke.

All of the participating subjects were capable of walking for more than 10 meters without aids (cane or ankle brace), and had decent cognitive ability with mini-mental state examination (MMSE) scores of over 24. Each of these patients had a passive angle on the affected side (ankle) greater than zero during the stance phase of the walking stage.

Moreover, those who had difficulty walking due to cardiovascular disease, and those who had ankle joint surgical histories were excluded from this study.

For the subjects of this study, exercise was not implemented two hours before measuring the change in the walking plantar pressure and asymmetry, in order to prevent changes due to motor learning. Moreover, to secure the reliability of the research data, three tests were conducted at the same time of day, for three days over one week, for each individual patient, and the average value was used for the statistics. All of the subjects participated in the walking measurements with bare feet, and did not use any walking aids. In this study, the treadmill speed of the subjects while walking was set where the patients felt most comfortable, and all of them walked at speeds between 1 km/hour and 2 km/hour. A safety pin was used so that the participants could instantly stop the treadmill for safety in case of emergency.

A treadmill (FDM-T system; zebris Medical GmbH, Isny, Germany) was used in this research to check the changes in the plantar pressure through GRF and symmetry during walking. This device had a length of 1.5 m and a width of 0.5 m, with 5,378 sensors attached to the bottom. The data were obtained via 120 Hz sampling.

All data are presented as means and standard deviation. An independent t-test and a χ^2 test were used to compare baseline demographic characteristics and diffrences between two groups. All statistical procedures were performed by SPSS (version 17.0, SPSS Inc., Chicago, IL, USA) with a significance level at 0.05.

RESULTS

The general characteristics of the study subjects are displayed in Table 1. In the both groups showed on the changes in the comparison of walking line and plantar pressure between the two groups (Table 2).

DISCUSSION

This study attempted to determine the impact of the form of muscle strength in the ankle plantar flexor of the affected side, among stroke patients suffering hemiplegia, on the changes in the walking line and plantar pressure.

In a walking evaluation, the changes in the walking line and plantar pressure (plantar surface) can be used as indices for abnormal walking or asymmetry. In general, it can be understood as a walking function that is important for the clinical recovery of hemiplegic patients after injury[11].

Normal plantar pressure consists of the heel-strike, stance phase, and push-off stages, in order. The weight loading reaction

Table 1. The demographic and clinical characteristics (N=30)

	Ankle MMT between poor and fair group (n=15)	Ankle MMT between zero and trace group (n=15)
Gender (male/female, n)	7/8	7/8
Age (years)	60.3 ± 5.3	58.6 ± 7.8
Height (cm)	164.9 ± 7.5	166.3 ± 7.9
Weight (kg)	167.0 ± 7.2	165.8 ± 7.1
Type (infaction/hemorrhage)	12/3	13/2
Duration of onset (month)	11.1 ± 3.7	10.7 ± 4.1

Values are presented as mean ± SD.

Table 2. Comparison of variables between the two groups (N=30)

	Ankle MMT between poor and fair group (n=15)	Ankle MMT between zero and trace group (n=15)
Length of gait line		
(affective/non affective)	152.8 ± 40.7/234.3 ± 64.4*	95.7 ± 36.0/245.9 ± 29.5
Change	81.5 ± 38*	150.2 ± 27.4*
% change	60.2 ± 3.5*	27.2 ± 6*
Single support gait line		
(affective/non affective)	56.6 ± 22.1/101 ± 38	43.3 ± 13.4/178.5 ± 34*
Change	49.8 ± 13.5*	135.2 ± 30*
% change	65.7 ± 4.5*	80 ± 4.1*
Lateral symmetry	−23.7 ± 7*	−31.4 ± 4.6*
Forefoot msximum pressure (affective/non affective)	15.8 ± 3.1/41.5 ± 71.5*	10.2 ± 3.4/24.5 ± 3.5
Midfoot maximum pressure (affective/non affective)	11.1 ± 2.9/13.5 ± 3.9*	8.5 ± 2.3/14.3 ± 3.4
Heelfoot maximum pressure (affective/non affective)	10.3 ± 3.3/19.1 ± 7.3	9.2 ± 3.1/19.6 ± 3

Values are presented as mean ± SD.
*p<0.05

against the GRF supports the weight from the ground to obtain a driving force during the heel-strike and push-off phases. Therefore, the normal GRF pattern is observed more often during the heel-strike for the vertical force and the push-off for the weight shift, rather than during the stance phase for weight loading[12].

In this study, the maximum ground pressure of the forefoot was more asymmetrically decreased in the lower limb of the affected side than the unaffected side. Similar to previous studies, patients with stroke show an asymmetrical and inefficient continuity of plantar pressure on the affected side, when compared to the unaffected side[13]. When examining the continuous change in the plantar pressure from the heel-strike, stance, and push-off phases, the plantar pressure in the unaffected side had a greater decrease than that in the affected side among hemiplegic patients (between poor and fair grade). Looking at the asymmetry in the same interval, the unaffected side showed a support rate of 54% in the heel-strike, 83% in the mid-stance, and 39% in the fore-foot, when compared to the affected side. Those hemiplegic patients whose affected side plantar flexor was between zero and trace showed a support rate of 47% in the heel-strike, 60% in the mid-stance, and 41% in the fore-foot. The ratio of the plantar pressure of the affected side against the unaffected side did not show a large difference between the two groups. However, the mid-stance ratio of those hemiplegic patients whose affected side plantar flexor was between zero and trace differed from the hemiplegic patients whose affected side plantar flexor was poor or fair. This can be attributed to the difficulty in strategic balancing and easy posture changes due to the decreased muscle strength in the affected side plantar flexor. It is conjectured that a dispersion of the center of weight took place, instead of an accurate plantar pressure change.

Moreover, it can be determined that the differences in the changes in the plantar pressure and plantar surface line are more asymmetrical when the muscle strength decreases, and more symmetrical when the muscle strength recovers. With regard to the gait line, hemiplegic patients whose affected side plantar flexor is between poor and fair showed differences between the unaffected and affected sides of 6:4 in a static situation and 6.5:3.5 in a dynamic situation, indicating more of a gait line in the unaffected side. Similarly, those hemiplegic patients whose affected side plantar flexor was between zero and trace also had differences of approximately 7:3 in the static situation and 8:2 in the dynamic situation, indicating more of a gait line in the unaffected side. Moreover, the hemiplegic patients whose affected side plantar flexor was between zero and trace showed a larger difference in the gait lines in the unaffected and affected sides in dynamic and static situations, when compared to the hemiplegic patients whose affected side plantar flexor was between poor and fair. This implies that the difference in the plantar flexor strength in the ankle affects the static and dynamic balances of the body shift. Moreover, we could also see that the insufficient muscle strength of the plantar surface affected the gait line.

Titianova et al. reported that the maximum plantar pressure decreases in the metatarsal area among hemiplegic patients. In addition, they argued that the walking of hemiplegic patients showed inefficient push-off, and that the toe had dependency during push-off. In the case of hemiplegic patients, the toe part of the affected side had greater maximum plantar pressure than the metatarsal part, while the healthy adults had greater maximum plantar pressure in the metatarsal part than the toe[14]. As shown in previous studies, an inefficient change in the plantar pressure affects the asymmetry of weight loading. According to the results of our study regarding the lateral displacement of plantar pressure for postural sway measurement, which can be an index for balancing ability, the experimental group (poor-fair) showed asymmetry with the lateral postural sway displacement at −23.7, and the control group (trace-zero) showed asymmetry at −31.4, indicating the importance of the plantar flexor muscle for postural sway.

The heel-strike is where the vertical shock to the GRF is absorbed during the early stage of walking, and push-off provides the driving force at the end of the stance phase. Stroke induced hemiplegia patients have lost the typical mechanism of the heel-strike and push-off, and they have a different form of GRF[15].

Due to the malfunctions in the heel-strike and push-off mechanisms, only one vertical plantar pressure was observed among the hemiplegic patients (instead of two). Therefore, the change in the plantar pressure from the heel-strike to the stance phases, or to the overall feet, became very short.

In clinical reasoning, the contact pattern of the plantar surface with the ground is a reliable method for walking analysis, which is an important index for understanding the ankle mechanism and the relationship between the plantar surface and the ground. However, with the use of walking aids or orthoses, this has not been sufficiently explained[16]. The previous studies were mainly focused on the change in the relationship between the plantar surface pressure and ankyloses in the lower limb of hemiplegic patients[17].

A small number of studies have examined the relationships between the changes in the plantar pressure of the lower limb among stroke patients with motor recovery. For example, Wong et al. argued that three types of GRFs were observed in the affected side of hemiplegic stroke patients[16].

Similar to previous studies, the changes in the length and dynamic pressure of the plantar surface during bipedalism could assess the improvement in the walking performance ability, as shown in this study. Moreover, they could measure the functional improvement, as well as help to build the therapeutic strategy. Furthermore, the functional improvement of patients with stroke could be supported through a verification of the analysis methods of the therapy strategy and walking pattern.

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