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Original Article

A study of structural foot deformity in stroke patients

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Abstract. [Purpose] The aim of this study was to evaluate the structural deformity of the foot joint on the affected side in hemiplegic patients to examine factors that affect this kind of structural deformity. [Subjects and Methods] Thirty-one hemiplegic patients and 32 normal adults participated. The foot posture index (FPI) was used to examine the shape of the foot, the modified Ashworth scale test was used to examine the degree of ankle joint rigidity, the navicular drop test was used to investigate the degree of navicular change, and the resting calcaneal stance position test was used to identify location change of the heel bone. [Results] The FPIs of the paretic side of the hemiplegic patients, the non-paretic side of the hemiplegic patients, and normal participants were −0.25 ± 2.1, 1.74 ± 2.3, and 2.12 ± 3.4 respectively. [Conclusion] Our findings indicated that in stroke-related hemiplegic patients, the more severe the spasticity, the more supinated the foot. Further, the smaller the degree of change in the navicular height of hemiplegic patients is, the more supinated the paretic side foot is. Additionally, a greater change in the location of the calcaneus was associated with greater supination of the overall foot.

Key words: Foot posture index, Hemiplegic foot, Foot deformity

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INTRODUCTION

Patients who have hemiplegia resulting from cerebrovascular diseases face a lot of difficulty in carrying out their daily activities due to motor disorder, sensory disorder, cognitive disorder, and language disorder; further, loss of gait restricts their activity level and lowers their functional independence[1)].

Gait disorder is common in stroke patients, and their gait patterns are characterized by a slow gait cycle and speed, difference in stride length between the paretic side and non-paretic side, and a long swing phase and short stance phase[2)]. In particular, the ankle joints not only absorb impact and advance the body, which are their primary functions, but also function as crucial joints for the ankle strategy in maintaining balance[3)]. Movement disorder in the ankle joint is an important cause of gait disorder[4)].

Structural deformity of the foot brings about functional change and therefore affects the maintenance of balance of the bilateral lower extremities and the trunk; such deformities may trigger abnormal changes in gait patterns and musculoskeletal system pain[5)]. Nonetheless, in the clinical field, it is difficult to analyze the shape of the foot because the equipment required is expensive and the procedure takes up a lot of time. The aim of this study was to examine the foot shape of hemiplegic patients by using the foot posture index (FPI), which is a simple measure of foot deformity in stroke patients in the clinical field; moreover, we used other fast readily available testing methods, i.e., the modified Ashworth scale (MAS) test, navicular drop test (NDT), and resting calcaneal stance position (RCSP) test, to understand how stroke affects foot joint deformity in hemiplegic patients. These methods do not require a lot of equipment or time, and the findings will provide guidance for future treatment strategies. Data from this study will provide the basis for studying functional changes in the feet of these patients.

SUBJECTS AND METHODS

The subjects of this study were hemiplegic patients who were diagnosed with a stroke through computed tomography or magnetic resonance imaging. They were capable of static standing. Their Korean mini-mental state examination (K-MMSE) scores were 24 points or higher, and they did not have any problems with cognitive function. The criteria for exclusion were vestibular or inner ear disease, peripheral sensory disorder, amputation of a lower extremity, severe joint disease, previous orthopedic surgery, diseases affecting gait such as Alzheimer's disease, and traumatic

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brain injury. The subjects in the control group were age-matched to those in the experimental group. Further, the control group participants had no neurological injury, waist pain, spondylarthritis, or rheumatoid arthritis; had not undergone orthopedic surgery; and had no pain or abnormality in the hip or knee joints. They were selected from normal adults who met the conditions for participation in this study and had no reason for disqualification. There were 31 patients in the experimental group (male, 20; female, 11; mean age, 63.4 ± 7.5 years; mean height, 167.4 ± 7.1 cm; mean weight, 65.2 ± 9 kg; BMI, 24.81 ± 16.8). Of the 31 patients, 18 had left hemiparalysis, and 13 had right hemiparalysis; the mean time since onset was 24.81 ± 16.8 months. There were 32 participants in the control group. (male, 21; female, 11; mean age, 63 ± 8 years; mean height, 167 ± 8.1 cm; mean weight, 65.1 ± 7.9 kg; BMI, 23.2 ± 1.5). The differences in general characteristics between the groups were not significant ($p > 0.05$).

All the subjects understood the purpose of this study and provided written informed consent prior to participation, in accordance with the ethical standards of the Declaration of Helsinki.

The FPI is a diagnostic tool devised to provide objective numerical values that reflect the condition of the foot—whether the foot is pronated, supinated, or neutral. The FPI consists of a total of six items scored on a five-point scale (−2, −2, 0, 1, and 2). When the sum of each measured value is a high positive number, the foot is considered to be pronated, while the lower the negative number of the sum is, the more supinated the foot[6].

The MAS is one of the most widely used methods to clinically evaluate the degree of muscle spasticity, which is defined as the degree of resistance felt in the muscles when an examiner passively bends or extends the joint of an examinee, who is in a lying position or in a relaxed state[7]. The MAS is scored on a six-point scale: 0, 1, 1+, 2, 3, and 4[8]. The present study measured the degree of spasticity of the ankle plantar flexors, which are known to greatly affect gait imbalance[9].

After the examinee sat in and maintained the subtalar neutral position, the examiner palpated the navicular tuberosity of the examinee, measured the height of the navicular bone using measurement equipment, and asked the examinee to stand on both feet. Then, the examiner measured again the height of the navicular bone and calculated the difference between the two measured values to obtain the result of the navicular drop test (NDT)[10–12]. In this study, a vernier height gauge (506-207; Mitutoyo, Kawasaki Japan) was used to measure NDT.

To measured the RCSP, the patient was laid in the prone position, and then the calcaneus was bisected using a bimanual technique, in which the point of dissection was marked and connected with a dot from the coronal plane[13]. The patient was asked to stand such that the gait angle and gait base were in line, and the angle between the vertical line and the bisected line of the calcaneus was measured using a gravity goniometer (MIE, Leeds, UK)[14]. The angle where the calcaneal slope and the ground met at the right angle was set as 0°, with minus values indicating inversion and plus values indicating eversion.

Table 1. Comparison of the results of the FPI test, NDT, and RCSP test among the non-paretic and paretic sides of the experimental group and the right side of the control group

	Patient group (n=31)		Control group (n=32)
	Paretic side	Non-paretic side	Dominant foot
FPI	−0.25±2.1*†	1.74±2.3‡	2.12±3.4
NDT	6.3±2.4*†	7.8±2.8‡	7.96±2.8
RCSP	0.22±2.5*†	−1.51±1.94‡	−1.68±2.5

Values are means±SE. FPI, foot posture index; NDT, navicular drop test; RCSP, resting calcaneal stance position
*p<0.05 vs. non-paretic side. †p<0.05 vs. control group, ‡p>0.05 vs. control group.

Statistical analysis of the data collected in this study was conducted using IBM SPSS Statistics for Windows (version 19.0). General information about the experimental group and the control group including weight, height, and body mass index was analyzed using an independent t-test. The results of the FPI test, MAS test, NDT, and RCSP test for the paretic and non-paretic sides of the experimental group and the left and right sides of the control group were compared using a paired t-test. An independent t-test was used to compare the paretic side of the experimental group and the dominant side of the control group. To examine the correlation between the results for the FPI, MAS, NDT, and RCSP, Spearman's correlation analysis was conducted. The significance level was set at $p < 0.05$.

RESULTS

The paretic side FPI of the patient group was 0.25 ± 2.1, while the non-paretic side FPI was 1.74 ± 2.3; the FPI of the control group was 2.12 ± 3.4. Of the 32 patients in the control group, 31 used the right foot as their dominant foot, and therefore the FPI obtained from the right foot was used as the control group value. The FPI of the paretic side of the hemiplegic patients and that of their non-paretic side were compared and found to be significantly different ($p < 0.05$). The FPI of the paretic side of the experimental group and that of the right side of the control group were also significantly different ($p < 0.05$). However, the FPI of the non-paretic side of the experimental group was not significantly different compared with the FPI of the right side of the control group ($p > 0.05$) (Table 1).

In order to investigate the degree of spasticity of the 31 stroke patients, the MAS of the plantar flexors on the patients' paretic side was measured. The numbers of patients with scores of 0, 1, 1+, 2, 3, and 4 were 8 (25.8%), 10 (32.3%), 11 (35.5%), 2 (6.5%), 0 (0%), and 0 (0%) respectively (Table 2).

The paretic side NDT value of the patient group was 6.3 ± 2.4, and the non-paretic side NDT value was 7.8 ± 2.8; the NDT value of the control group was 7.96 ± 2.8. In the hemiplegic patients, the NDT value of the foot joint on the paretic side was significantly greater than that of the foot

Table 2. Result of the MAS test

MAS score	Frequency (n=31)	Percentage (%)
0	8	25.8
1	10	32.3
1+	11	35.5
2	2	6.5
3	0	0
4	0	0

MAS, modified Ashworth scale

joint on the non-paretic side ($p < 0.05$) and that of the right side of the control group ($p < 0.05$). There were no significant differences between the NDT value of the non-paretic side of the hemiplegic patients and that of the right side of the control group ($p > 0.05$) (Table 1).

The paretic side and non-paretic side RCSPs of the experimental group were 0.22 ± 2.5 and −1.51 ± 1.94 respectively, while the RCSP of the control group was −1.68 ± 2.5. The RCSP, as measured for the paretic side of the hemiplegic patients, was significantly different from that measured for the non-paretic side ($p < 0.05$) and was also significantly different from that of the right side of the control group ($p < 0.05$). There were no significant differences between the RCSP of the non-paretic side of the hemiplegic patients and that of the right side of the control group ($p > 0.05$) (Table 1).

In order to examine the effects of the MAS score of the paretic foot joint of hemiplegic patients on the FPI, NDT, and RCSP results, the correlation between them was examined. There was a strong negative correlation between the results of the MAS and FPI tests ($r = 0.78$), and there was a weak negative correlation between the results of the MAS test and NDT ($r = -0.47$). However, a positive correlation was observed between the results of the MAS test and RCSP test ($r = 0.567$).

Further, in order to examine the effects of the modified FPI test on the results of the NDT and RCSP test, the correlation between them was examined. The results of the FPI test and NDT were positively correlated ($r = 0.603$), while those of the FPI and RCSP tests were strongly negatively correlated ($r = -0.720$). The results of the FPI test indicated that smaller differences in the results of the NDT were associated with greater supination and less pronation of the foot. In addition, according to the results of the FPI test, when a subject's calcaneus was observed to be leaning outwards, his or her RCSP had a positive value, and the foot had an overall supinated shape.

DISCUSSION

Hemiplegia resulting from a stroke causes changes in the range of motion, muscle strength, and senses of the foot due to musculoskeletal or neurological system abnormalities, and such structural deformities of the foot bring about functional changes and therefore affect maintenance of balance of the bilateral lower extremities and the trunk. Such deformities may trigger abnormal changes in overall gait patterns and musculoskeletal system pain[5)].

The present study employed the FPI to differentiate between foot shapes: the FPI values of the non-paretic side of the hemiplegic patients and the control group were within the normal range. The FPI values of the control subjects were similar to the average FPI value (1.9 ± 2.0) of healthy subjects examined by Redmond et al[15)].

The NDT was used as another method to examine structural deformities affecting foot shape. When the hemiplegic patients changed their position from a neutral subtalar joint position to a standing position, the drop on the paretic side was greater than that on the non-paretic side and that of the control subjects. This could have been caused by various reasons.

The RCSP test was also employed to examine foot shape. In this study, the foot joints of the hemiplegic patients on the paretic side were found in eversion than those on the non-paretic side. The results indicated the feet of the hemiplegic patients on the paretic side had an overall supinated shape. It was supported with the strong negative correlation between the RCSP and the FPI.

Barnes[16)] noted that spasticity of the lower limbs triggered abnormal muscle tension by mutual contraction of the protagonist and the antagonist muscles, and such abnormal muscle tension may act as a positive element in a standing position or during gait but is a major cause of decreased gait ability in stroke patients. Thus, it seems that the degree of spasticity greatly influences the slope of the calcaneus. The results of the NDT and FPI test also showed a high correlation, which implies that the larger the drop of the navicular bone, the more pronated the foot.

The results of this study are consistent with those of Billis et al.[17)], in which a high correlation was reported between navicular drop and foot inversion/eversion. Park et al.[18)] found that hemiparetic patients demonstrated increased weight bearing on the forefoot and lateral foot edge, which made weight bearing harder. Consistent with the results of Park et al., this study showed lower NDT values in subjects with higher tone, which can be attributed to difficulty in putting weight onto the medial edge of the foot. Further, Sackley[19)] reported that 61 to 80% of the weight of stroke-related hemiplegic patients was borne by the non-paretic side lower extremity. The causes of asymmetric weight load are abnormal muscle activity, abnormal position dynamics, and sensory disorder[20, 21)]. According to the present study, increased spasticity, changes in the navicular location, and changes in the calcaneal location triggered by a stroke led to supination of the foot on the paretic side, which causes abnormal weight support. These changes were found to be closely correlated with each other.

According to the research results, the joint of the supinated foot of stroke patients had a high score in the MAS test as well. Thus, as shown by the other tests too, the higher the degree of spasticity, the more supinated the foot; moreover, patients whose degree of change in the navicular bone was low exhibited a high degree of spasticity and supination of the foot joint. The RCSP test results showed that changes in the calcaneus were associated with a more lateral location of the calcaneus, a higher degree of spasticity, a smaller change in the navicular bone location, and greater supination of the foot. These data verified that structural deformity of the foot brought about by hemiplegia resulting from a stroke occurs due to various factors and that these factors are highly correlated.

Thus, the findings from this study shed light on the morphological changes in the foot joint of hemiplegic patients. Moreover, since the results of the various tests showed high correlation and since these tests are simple and quick, these findings may have future clinical uses. The findings can therefore be used in therapeutic strategies for patients and lay the basis for future similar research.

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