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Plantar Pressure Difference: Decision Criteria of Motor Relearning Feedback Insole for Hemiplegic Patients

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Abstract. The feedback in the motor relearning approach is important and useful for hemiplegic patient training. Plantar pressure is clinically relevant to assess the foot function. This study proposed the decision criteria of insole feedback designed for the motor relearning approach using plantar pressure. The operating concept of the insole feedback was also presented. The Pedar-X® system was used to measure the plantar pressure in normal people and hemiplegic patients. We calculated the plantar pressure difference (PPD) from the maximum pressure picture (MPP) and the mean value pressure (MVP). The values of PPD calculated from MPP were 4.59±1.86% and 29.85±10.79% whereas the PPD calculated from MVP were 4.28±3.87% and 25.06±9.47% in normal person and patient groups, respectively. We suggest using the PPD calculated from MPP as the decision criteria for the insole feedback because this value was clearly distinguished between groups, less variation and easy to obtain. However, the motor relearning program using this insole feedback should be individually designed for patient such as the set point of PPD for the decision criteria and time of training. Moreover, it is necessary to evaluate the patient satisfaction after using the feedback insole to improve the prototype of the shoes.

Keywords: plantar pressure, insole, feedback, motor relearning, hemiplegic

1. Introduction

A common problem of hemiplegic patients is the balance disorder which depends on the area of damaged brain. Walking patterns in hemiplegic patients are different compared with normal people [1]. The goal of walking training in hemiplegic patients is to make the plantar pressure on a hemiplegic side to be similar to a normal side. Motor relearning program technique focuses on the feedback to let the patients know the development of their training[2].

The plantar pressure measurement is clinically relevant to assess the foot and ankle biomechanical function. Several studies reported that the Pedar-X® system, an in-shoe dynamic pressure measuring system, has good repeatability and accuracy in plantar pressure measurement in many conditions [3, 4]. Sensor-embedded shoes with fuzzy logic algorithm developed by Kong and Tomizuka was proposed to assess the abnormalities in a human gait [5]. Using plantar pressure measurement, we conceptually developed the motor relearning insole feedback for hemiplegic patients during walking training. Our study measured the plantar pressure using Pedar-X® in normal people and hemiplegic patients to identify the decision criteria of insole feedback.

2. Materials and Methods

2.1. Sensing material

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The force sensitive resistor (FSR) is the pressure sensor used to measure the dynamic force. There is a type of resistor that the resistance changes when the force or pressure is applied therefore its resistance depends on force or pressure applied on the sensing area. Furthermore, FSR is very simple to use and inexpensive compared to other types of sensors. The FRS characteristics are presented in Table 1.

Table 1: Force sensitive resistor (FSR) characteristics

Overall length	2.375”
Overall width	0.75”
Active area	0.5” diameter
Force sensitive range	100 g to 10 kg
Force repeatability (Single part)	± 2%
Hysteresis	+ 10%

2.2. Insole structure

Five FSRs are located under the insole based on anatomical information. The sensors are embedded in three areas; heel, metatarsal and hallux. There are two sensors at the position of heel, one at the first metatarsal, one at the fourth metatarsal and one at the area of hallux as shown in Fig.1. It has been demonstrated that higher pressure is found in these three areas during normal activities [5-8]. The insoles were attached to wearable measurement system that measures the ground reaction force while walking. The controller box contained an analog to digital converter is put underneath the insole and connects to the sensors as presented in Fig. 2.

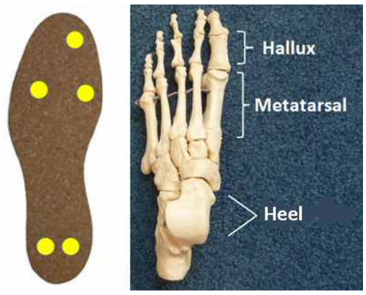

Fig. 1: Positions of FSR under the insole.

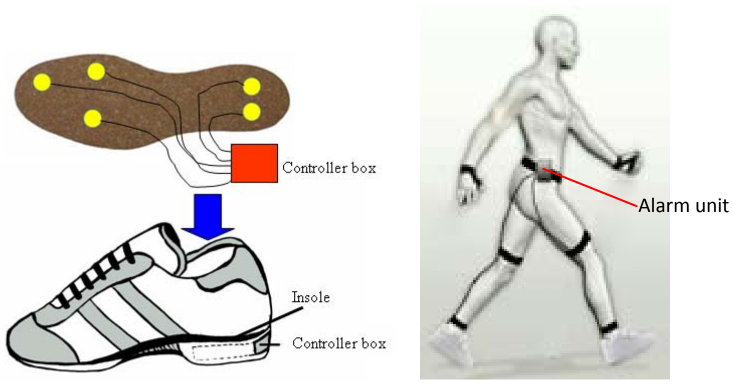

Fig. 2: Layout of the prototype for insole-feedback shoes.

2.3. Plantar pressure measurement

We measured plantar pressure using the Pedar-X® system in two experimental groups; normal person and hemiplegic patient groups. A normal person group included 15 males and 9 females whereas a hemiplegic patient group, attending the service for physical therapy unit at Songklanagarind hospital, had 5 males and 3 females. The inclusion criteria of normal persons for this study were: age ranged from 41 to 60 years, no previous surgery, no history of trauma and no limb discrepancy. The lower limb discrepancy was defined by the equal length of anterior superior iliac spine to medial malleolus while standing between left and right sides. The inclusion criteria for patients involved in our study included a history of cerebrovascular disease, age more than 41 years and a presence of balance disability. Subject was asked to wear sport shoes and walk along a distance about 10 meters for 3 rounds. The experiment was repeated 3 times in each subject. At the end of each time, subject took a rest for 3 minutes before starting the test again. Plantar pressures acquired from the Pedar-X® system were in terms of the maximum pressure picture (MPP) and mean value pressure (MVP).

MPP is the maximum force values in each sensor divided by the number of loaded sensor while MVP is the average of mean value in all frames of gait. We calculated the difference of plantar pressure in term of MPP and MVP either normal or hemiplegic patient groups.

2.4. Data processing concept

The operating concept of the insole feedback after data acquisition is shown in the flowchart of Fig. 3. In brief, the average pressure of each side will be calculated if all sensors have value. The percentage of the plantar pressure difference (PPD) was then calculated as expressed in (1). The decision criteria of the insole feedback for the motor relearning were based on the PPD. Therefore, we used PPD in a normal group as a target of the motor relearning program. If the PPD obtained from the sensors is greater than the target PPD, the alarm unit will acknowledge the patients that their plantar pressure on both sides is different and needs to be adjusted.

$$PPD = \frac{2(P_{Left} - P_{Right})}{P_{Left} + P_{Right}} \times 100 \tag{1}$$

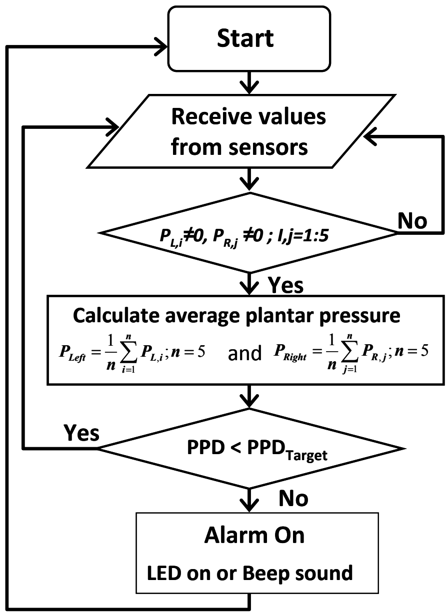

Fig. 3: Flow chart of data processing for insole feedback.

3. Results

3.1. Percentage of plantar pressure difference

PPD during walking calculated from MPP and MVP between left and right sides is presented in Fig.4. There were statistically significant differences in both MPP and MVP between the normal person group and the hemiplegic patient group. The values of PPD calculated from MPP were 4.59±1.86% and 29.85±10.79% in normal person and patient groups. In addition, the values of PPD calculated from MVP were 4.28±3.87% and 25.06±9.47% in normal person and hemiplegic patient groups. It clearly indicates that the PPD was higher in the hemiplegic patients and significantly different compared to normal people (*$p<0.05$*). Therefore, we can use PPD to identify hemiplegic patients and be the decision criteria for the motor relearning program.

When we focused PPD in the normal person group, we found that PPD calculated from MPP was not varied due to the age, unlike PPD calculated from MVP as demonstrated in Fig.5. The mean value of PPD calculated from MPP was ~5% in all three ranges of age. In contrast, it seems that the mean value of PPD calculated from MVP increased when the age increased. However, this result might be related to less loaded areas for plantar pressure when people get older.

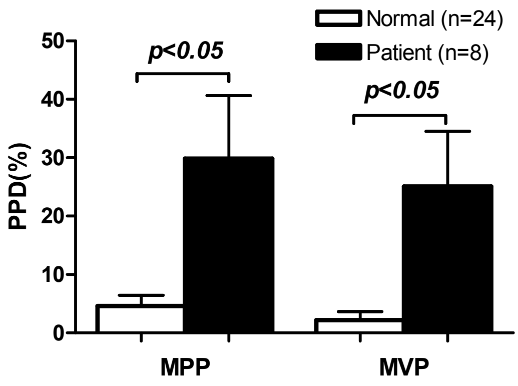

Fig. 4: The percentage of plantar pressure difference (PPD) while walking calculated from MPP and MVP in normal persons and hemiplegic patients.

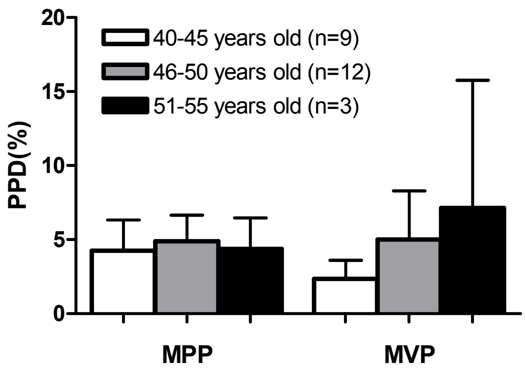

Fig. 5: The percentage of plantar pressure difference (PPD) while walking calculated from MPP and MVP in normal persons classified by age.

3.2. Weight testing of insole feedback

Using a casting foot combined with fitness drum bells as the testing weights, it was found that the output voltage from the controller box linearly increased with the testing weight as shown in Fig.6. However, there was residue output voltage even though there was no weight on the sensors.

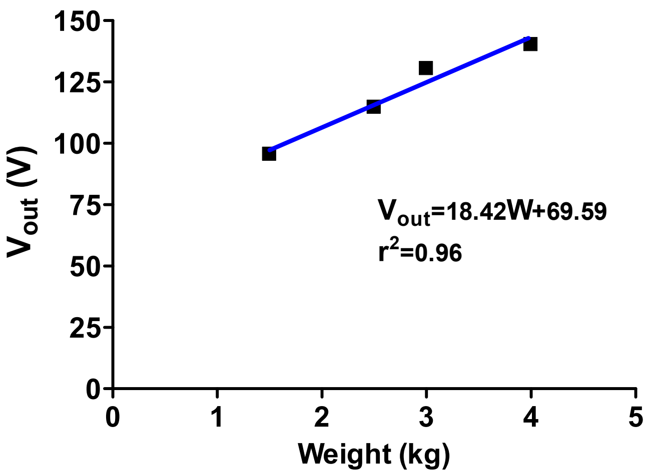

Fig. 6: The relationship between testing weights and output voltages of the controller box

4. Discussion and Conclusions

In this paper, we measured plantar pressures and found that there was a vast difference in the ground reaction force between hemiplegic side and normal side during walking in stroke patients compared to that in normal persons[9]. We therefore proposed the value of PPD to be used as decision criteria of insole feedback in motor relearning of hemiplegic patients.

The value of PPD calculated from MVP was lower than that calculation from MPP due to the calculation method of mean and peak values. The variation of PPD in patient group was greater compared to the normal group. This variation was the result of severity and training period of patients[10]. Our results significantly showed that hemiplegics patients had PPD calculated from either MPP or MVP about 20% to 25% higher than normal persons. We suggest using the PPD calculated from MPP as the decision criteria for the insole feedback because this value had more different between groups and not complicate to obtain. Therefore, in order to perform a motor relearning program for the hemiplegic patient, it is necessary to gradually lower, stepwise-like pattern, the plantar pressure difference between a hemiplegic side and a normal side toward the target value of normal person (PPD=5%) [2].

However, the motor relearning program using this insole feedback should be individually designed for patient such as the set point of PPD for the decision criteria and time of training. Therefore, it is important to know about the age, symptom, severity and therapeutic program of patient.

In future work, we would like to validate our insole feedback with the decision criteria of PPD during walking of normal people and patients. We would also like to increase the number of subjects, both normal people and hemiplegic patients, to finalize the target PPD. Moreover, it is necessary to evaluate the patient satisfaction after using the feedback insole to improve the prototype of the shoes.

5. Acknowledgements

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