An Evaluation of the Center of Pressure by the Multi-Layers Rubber Mats Using Image-base Rapid Pressure Measuring System

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Abstract
The Multi-Layers Rubber Mats (MLRM) ink footprint has been used to analyze plantar pressure in qualitative data and foot arch index for the customized insole which reflected pressure beneath barefoot. In this study, the MLRM was evaluated the center of pressure (COP) in quantify data by image-base measuring system. The footprint in static and dynamics states were performed to investigate significant difference of the COP. Subsequently, the COP results were compared with a pressure platform. The results showed that, there were some estimate disparity in X_{COP} *(17.4%,* $p<0.001$*) and showed good relationship on the* Y_{COP} *(4.23%,* $p=0.278$*) coordinate where compared with the pressure platform. Then, the COP from dynamic state which affected of accumulated pressure during performed dynamic action and the results showed good relation in disparity to static state. Therefore, the evaluation of the COP by image-base measuring system is helpful for clinician or insole maker which able to check the COP from MLRM ink footprint.*

Keywords: *Center of pressure, Multi-Layers Rubber Mats, Image-based measuring system, Plantar pressure*

1 Introduction

Shoe insole reduces the high pressure from forefoot and heel areas to midfoot area by increasing the area fitted to the foot arch [1-2]. According to the foot shape are difference, especially for the patients with foot disease or abnormal in plantar shapes, the insoles should be fitted individual by using a customized insoles. The customized insoles development has been done in several ways [1-5]. Also, to fit the insoles individual, the clinicians or insole makers diagnose various foot functions on several types of equipments such as an ink footprints or a plantar pressure measurements. The ink footprint is the traditional way to achieve various foot functions such as foot contact area, foot arch index and foot length. The plantar pressure measurement is uses to investigate the plantar pressure, foot functions or the center of pressure (COP).

The COP is a force on the plantar surface which is a component of the vertical ground reaction force reacting with the surface of the foot [6]. It has been used for measure of balance [7] and indication of foot function [8].

A useful of pedograph first described by Harris and Beath (1947) has been used to analyze plantar pressure in qualitative data and foot indexes which reflected grid densities of pressure beneath barefoot by Multi-Layers Rubber Mats (MLRM) [9]. The instrument provides qualitative plantar pressure and foot arch index with simplistic, inexpensive, and reliable. Otherwise, there has no investigated the evaluation of the COP from the MLRM to check to balance of the body.

Therefore, the purpose of this study was to evaluate the COP from MLRM in qualitative data to quantify data during static and dynamics state by using image-based rapid pressure measuring system (IBRPMS). Then, the results were compared with the commercial plantar pressure measurement base on pressure platform (PP).

2 Materials and Method

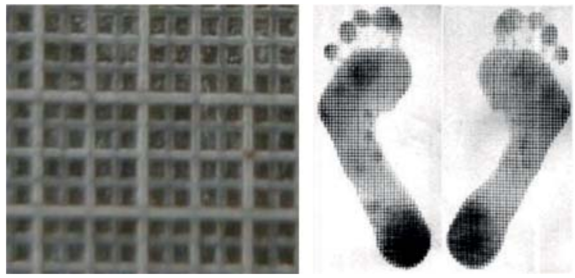
2.1 *Subjects and equipment*

Fifteen healthy male graduated students (age 24.2±2.3 year; mass 67±10.8 kg; height 171.5±6.6 m) were participated. The subjects had no foot abnormalities and injury on their lower limp.

All measurements were performed on MLRM and PP. The MLRM (Good Arch Ltd., Taiwan) is easy to recognize the pressure distribution by eyes from the grid densities. The mechanism is that when the pressure applied though the MLRM which much more pressure it will appear inner grid layer. The rubber pad dimension 355 mm x 165 mm, 1.5 mm in thickness and height from ground 6 mm, the main grid consists three grid layers inside (Figure 1(a) and 1(b)). The sample footprints of different subjects and conditions show in Figure 2.

The PP (Tactilus, Pressure Mapping System, Madison, USA) was used to investigate the COP. The details of sensor size, sensor point size and number of grid is 40.894 cm × 40.894 cm, 1.278 cm × 1.278 cm and 32 × 32 units, respectively.

In this study performed static and dynamic states. The static state was performed on the Multi-layers Rubber Mat (MLRMS) and PP to represent the COP during standing (see Figure 3(a)). The dynamic state was performed only in Multi-layers Rubber Mat (MLRMD) to assume the human activity for investigation the peak pressure on plantar during activity by continue moving the body with bending the knee (Figure 3(b)).



(a) (b)

Figure 1: The MLRM: (a) The Multi-layers grid. (b) A sample footprint from MLRM.

(a) (b) (c) (d)

Figure 2: Showing sample of multiple images of different conditions: (a) Subject A (bodyweight 62kg) on static state. (b) Subject A on dynamic state. (c) Subject B (body weight 55kg) on static state. (d). Subject B on dynamic state.

(a) (b)

Figure 3: (a) Static state. (b) Dynamic state.

2.2 *Mathematic transformation*

In this study, the MLRM provides grid densities of pressure varying by the higher grid density represent higher pressure. The idea is similar to an IBRPMS proposed by Chang et al. [4-5] (see Figure 4). The mathematic model was adopted by the IBRPMS to allow calculating the COP from MLRM. Chang et al. described the transformation model for IBRPMS that: when the feet support a person's weight, the downward pressure extrudes the blood out of the soles' capillaries. This generates a different color in regions where the

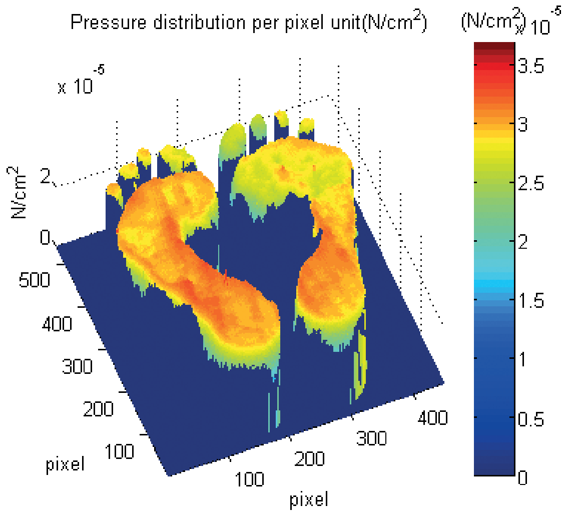


Figure 4: The sample result of the IBRPMS that measures the plantar pressure on the basis of the sole image proposed by Chang et al [3-5].

soles make ground contact, owing to the difference of local contact pressures. Then, the whiter the color is, the larger the plantar pressure is. So, the total body weight is proportional to the sum of the digital gray scale (digital binary 8 bits) values in all regions:

$$G^k = \sum_{i=1}^{m}\sum_{j=1}^{n} g_{i,j} \tag{1}$$

where G^k is the gray scale value of the kth region, $g_{i,j}$ is the gray pixel value in (i, j), i and j are the x and y coordinates, and m and n are the maximum values in the x and y coordinates in the kth region. In this case, the total body weight W is

$$W = \sum_{k=1}^{n} W^k \tag{2}$$

W^k is the distributed load in the kth region:

$$W^k = f \cdot \left\{ \frac{G^k}{\sum_k G^k} \right\} \times W \tag{3}$$

where f is an adjustment factor based on conditions such as the insole material, the specific physical activity, and the person's health. The constant f functions as an adjustable factor for summing up the distributed loads W^k as equal to the total body weight W. Then, the redistributed pressure in each region is

$$P^k = \frac{W^k}{A^k} \tag{4}$$

where A^k is the area of the kth region. In this case, applied Eq. (3) and (4), then we can see that the pressure also is proportion with the digital gray scale following:

$$\frac{P^k A^k}{\sum_k P^k A^k} = \frac{W^k}{W} = f \cdot \left\{ \frac{G^k}{\sum_k G^k} \right\} \tag{5}$$

Then, the standard COP formulates [10] were considered that summarized below:

$$X_{cop} = \frac{\sum_k P^k A^k X^k}{\sum_k P^k A^k} \tag{6}$$

$$Y_{cop} = \frac{\sum_k P^k A^k Y^k}{\sum_k P^k A^k} \tag{7}$$

where (X_{COP}, Y_{COP}) is the coordinate of the COP, (X^k, Y^k) is the position of the pixel in x and y coordinate.

Then, we applied Eq. (5) into (6) and (7) to calculating the COP from digital gray scale following:

$$X_{cop} = f \cdot \frac{\sum_k G^k X^k}{\sum_k G^k} \tag{8}$$

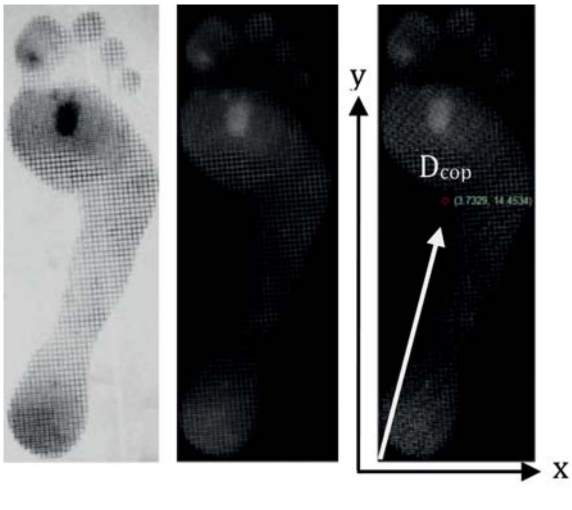
$$Y_{cop} = f \cdot \frac{\sum_k G^k Y^k}{\sum_k G^k} \tag{9}$$

Therefore, the COP can be evaluated by gray scale values in Eq. (8) and (9) from footprint or sole image.

2.3 *Data acquisition and statistical analysis*

The MLRMS was obtained following: to achieve right footprint, a pad of MLRM impregnated with ink then placing left foot on ground supporter and placing right foot slightly on the pad, after acquirement right footprint then remove right foot slightly and left foot, respectively [11]. The task of dynamic state followed static footprint and moving body by go down the knees before remove both feet. The static state of PP was obtained by the subject stand on the platform on nature posture during 100 seconds, the convenient good of the COP result was selected during stable posture.

The software was performed to calculate the



(a) (b) (c)

Figure 5: (a) Gray scale image input. (b) Inverted of gray scale image. (c) The inner tangent axis with the results in X_{COP}, Y_{COP} and D_{COP}, the D_{COP} was calculated by $\sqrt{X_{COP}^2 + Y_{COP}^2}$

COP by using MATLAB (MathWork, U.S.A.). The right foot was select to evaluate and compare the COP. The details of image capturing system could described that, (1) the footprints were scanned by scanner in dimensions of 1275x1755 on the Joint Photographic Experts Group (JPEG) format, (2) the footprint images were converted into grayscale Figure 5(a), (3) the grayscale image were inverted the color (black to white) Figure 5(b), (4) the footprints were calibrated from known actual scale, (5) rotating the footprint to inner tangent axis, (6) cropping the image close to interested region, and (7) calculating the COP from gray scale values by applied Eq.(8) and (9) then the results were report in X_{COP}, Y_{COP} and displacement of COP (D_{COP}) by illustrated in Figure 5(c).

The three replication results were used on statistical purpose. The pair between methods was compared using sample t test (95% confidence interval) and Mann Whitney U test according to the normal distribution, if necessary.

3 Results

Forty-five experimental image results (15 subjects x 3 replication) were used in this study. A sample of footprint images and sample of calculating the COP result show in Figure 2 and Figure 5(c), respectively. The mean ±S.D. results show in table 1. The X_{COP}, Y_{COP} and D_{COP} from three methods are shown in Figure 6, Figure 7 and Figure 8, respectively. The results in X_{COP}, Y_{COP} and D_{COP} were used to calculate the percentage disparity to indicate the different between pair methods. The pair methods were groups by the comparison of the PP-MLRMS, PP-MLRMD, and MLRMS-MLRMD. Moreover, the statistical *p*-value was used to identify statistical significant of pair methods.

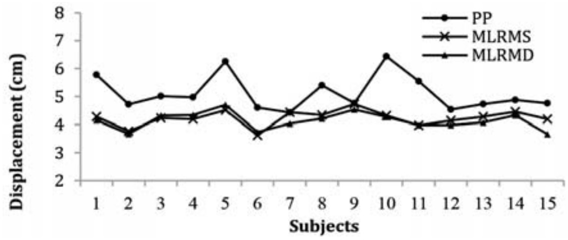


Figure 6: The X_{COP} on x coordinate.

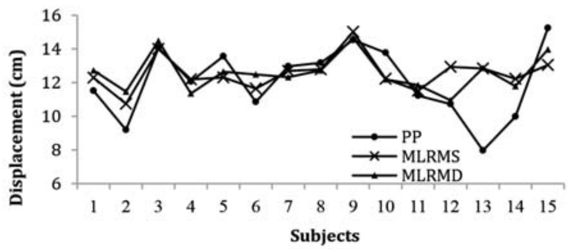


Figure 7: The Y_{COP} on y coordinate.

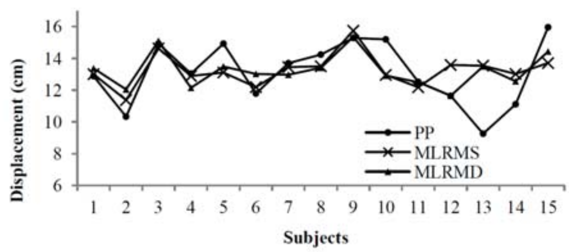


Figure 8: The D_{COP} on (x, y) coordinate.

Table 1: The mean ±S.D. results from fifteen subjects

	PP	MLRMS	MLRMD
X_{COP}	5.12±0.62	4.23±0.28	4.13±0.30
Y_{COP}	12.05±2.08	12.56±1.01	12.56±1.09
D_{COP}	13.82±1.68	13.40±0.97	13.49±1.06

The percentage disparity and the *p*-value from *t*-test pairs between methods show in Table 2. The percentage disparity shows large error at the X_{COP} on the pairs of PP-MLRMS and PP-MLRMD by 17.4% and 19.3%, respectively. Statistical significant difference were identified between the pairs of PP-MLRMS and PP-MLRMS on the X_{COP} ($p<0.001$).

Table 2: The percentage disparity and the *p*-value from *t*-test pairs with 95% confidence interval of the difference

		PP-MLRMS	PP-MLRMD	MLRMS-MLRMD
X_{COP}	Percentage[1]	17.4	19.3	2.36
	p-value	<0.05	<0.05	0.067
Y_{COP}	Percentage[1]	-4.23	-4.23	0
	p-value	0.278	0.258	0.977
D_{COP}	Percentage[1]	3.04	2.39	-0.67
	p-value	0.288	0.399	0.626

[1]Percentage = ((data$_1$-data$_2$)/data1)*100, positive indicated data$_1$>data$_2$

4 Discussion

The overall evaluation results showed good relation to the commercial plantar pressure base on pressure platform. Some large percentage disparity occurred at the X_{COP}, this showed the sensitivity effect of small distance in x-direction when compared to the y-direction. Otherwise, there are some different characteristic when take the footprint by MLRM such as accumulates inks print during taking footprint when body moving when compare with the PP that does not show the accumulation effect which capture the COP in individual times.

The static and dynamic states were performed to investigate the COP between methods. The COP result showed good relationship in all directions with the static state. The dynamic state captured and accumulated the pressure during moving the body. In this point, the plantar pressure on dynamic state showed higher pressure than static state, therefore, the pressure on dynamic state is proportional with static state in a constant factor.

Our current study examined the COP from Multi-layers Rubber Mat (MLRM) which assists the clinician or insole maker to diagnose the balance of the body reflected from plantar pressure which related to uncomplicated, inexpensive and reliable of MLRM. The evaluation COP by image-base measuring system can be developed such as convenient software to check the COP from the footprint image of MLRM.

5 Conclusions

The evaluation of the COP by image-base measuring system from MLRM on static and dynamic states had been investigated in this study. The COP results were compared with the pressure platform. The results showed that, some estimate disparity in X_{COP} (17.4%, $p<0.001$) and showed good relationship on the Y_{COP} (4.23%, $p=0.278$) coordinate where compared with pressure platform. Then, the COP from dynamic state which affected of accumulated pressure during performed dynamic action and the results showed good relation to static state.

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