The Foot Feature Measurement System and Its Application to Postural Stability of Healthy Subjects

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Abstract: In this study we aimed to develop a foot feature measurement system (FFMS) being able to simultaneously extract foot feature parameters in both static and dynamic condition. In addition, we investigated how these foot features are associated to the postural stability through human experiments as this is one of the most important requirements for natural and aesthetic gait pattern. From all thirteen subjects participated in this study, this foot arch mechanism were clearly observed. It indicates that observation of LLA and area of MLA curves is important to investigate postural stability in accordance with the different type of foot arches. For the conclusion, foot anatomical characteristics such as height and the area of each arch curves can be observed in both static and dynamic condition using the FFMS. In addition, it can be concluded that the FFMS can provide more precise and various foot information by considering the LLA during both static and dynamic condition.

1 INTRODUCTION

Recently, studies on designing subject-specific shoes and insoles have been actively proceeded, to decrease an impact force and stress applied at foot and to increase a performance of the sports related movements. Especially, a foot mechanism which is static and dynamic changes of foot arch is the most important factor to determine the performance of gait and other activities. Thus, identifying this mechanism is necessary for establishing the design of personalized shoe insole. The foot arch, comprised of medial longitudinal arch (MLA), lateral longitudinal arch (LLA), and transverse arch, significantly contributes to the body weight support, shock absorption, body propulsion, and postural control during walking and running (Wright et al., 2012, Daentzer et al., 1997, Chang et al., 2014). However, most of currently available personalized insoles are generally manufactured by contemplating the structure of MLA in static condition without considering the LLA structure and dynamic circumstances (Shirmohammadi and Ferrero, 2014, Uhm et al., 2015, Coudert et al., 2006).

Therefore in this study we aimed to develop a foot feature measurement system (FFMS) being able to simultaneously extract foot feature parameters such as foot length, foot width, the height of MLA and LLA in both static and dynamic condition. In addition, we investigated how these foot features are associated to the postural stability through human experiments as this is one of the most important requirements for natural and aesthetic gait pattern.

2 METHODS

The FFMS system is shown in Fig 1. Overall FFMS is composed of a measurement system and analysis modules. The measurement system is comprised of a runway and a scanning stage. The runway is a wooden structure of 200cm (length) x 70cm (width) x 45cm (height), and the scanning stage is composed of a depth camera embedded underneath the transparent acrylic panel and four uni-axial force sensors at corners of the panel. The depth camera is built in to measure morphological characteristics of foot and geometric structure of the foot arch, while the force sensors are set up to investigate the stability of movements which is a center of pressure (CoP) of the foot (Fig. 1B). All the obtained images and CoP data were stored in an in-house developed software.

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Analysis modules then can be used to extract the foot features from the images obtained by the FFMS.

To evaluate the feasibility of the FFMS and to investigate relation of foot features and postural stability, thirteen healthy young subjects were participated in the experiment. The experiment is comprised of sitting (static condition), walking (dynamic condition), and one leg standing (OLS). The foot features such as the curves and heights of MLA and LLA were extracted in both static and dynamic conditions. In addition, temporal trajectory of center of pressure (CoP) were obtained and anterior-posterior (AP) CoP distance was calculated during OLS condition. For the dynamic condition, the foot parameters were calculated in the mid-stance, where the ground reaction force acting on the foot was the maximum. The MLA curve is defined along a foot skin surface by connecting a representative point on the calcaneus and the 1st metatarsophalangeal (MTP) joint. Similarly the LLA curve is defined by connecting a point on the calcaneus and the 4th MTP joint. Correlations between foot features and CoP distance were calculated to investigate relations of the parameters.

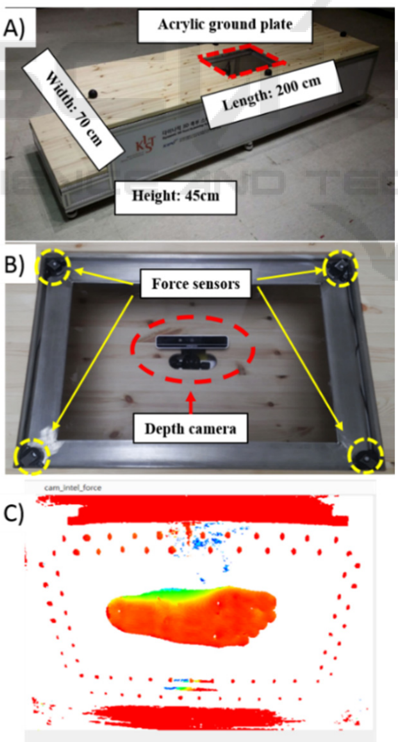

Figure 1: System installation of FFMS, A) scanning stage of the proposed system, B) Depth camera beneath the transparent acrylic board, and C) an example of a depth image of a foot.

Table 1: Mean and standard deviation of foot arch parameters in both static and dynamic conditions.

Foot Parameters		Mean (mm)	SD (mm)
Height MLA	Static	11.45	1.40
	Dynamic	9.55	1.56
Height LLA	Static	4.78	1.13
	Dynamic	3.93	1.11
Area MLA	Static	5818.10	916.54
	Dynamic	4972.65	927.45
Area LLA	Static	1495.74	415.88
	Dynamic	1254.20	365.60

3 RESULTS

The curves of MLA and LLA during both static and dynamic conditions were shown in Figure 2, and calculated maximum heights and curve areas which are the integral of the arch curves were presented in Table 1. The heights and areas decreased significantly in dynamic condition at both MLA and LLA. Table 2 shows the correlation coefficients between arch parameters and CoP distance in AP direction. The maximum height of LLA curves and area of MLA curves are moderately correlated with the CoP distance.

4 DISCUSSION

In this study, we were able to extract geometric changes of the medial and lateral longitudinal arch curves as well as their height and area from the static and dynamic conditions using newly developed FFMS. The MLA height is lowered in weight bearing condition compared to non-weight bearing condition. It is because once entire foot is on the ground, the foot has to endure downward force caused by body weight (Stolwijk et al., 2014, Fukano and Fukubayashi, 2009). From all thirteen subjects participated in this study, this foot arch mechanism were clearly observed.

In addition, the height of LLA in dynamic condition as well as the area of MLA in both static and dynamic conditions had positively moderate correlations with CoP distance in AP direction. It indicates that observation of LLA and area of MLA curves is

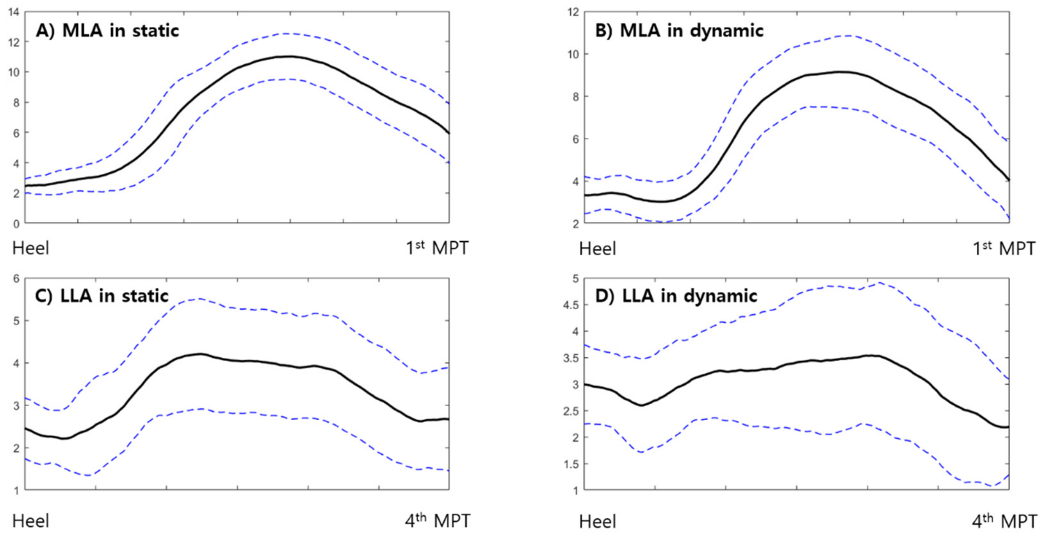

Figure 2: MLA and LLA curves and their standard deviations in static and dynamic conditions. Black line shows the averaged arch curves of thirteen subjects, and blue line shows the standard deviations (mm).

important to investigate postural stability in accordance with the different type of foot arches since each longitudinal arch has a different respective function (Fukano and Fukubayashi, 2009).

For the conclusion, foot anatomical characteristics such as height and the area of each arch curves can be observed in both static and dynamic condition using the FFMS. In addition, it can be concluded that the FFMS can provide more precise and various foot information by considering the LLA during both static and dynamic condition. Therefore we expect that foot shape related studies for various sports activities, and studies establishing protocols to prevent injuries caused by the foot deformity will be actively performed by quantitatively measuring and analysing the foot parameters using the FFMS.

Table 2: Correlation coefficient between foot arch parameters and CoP distance in AP direction.

		AP CoP distance	
		r	p
Height MLA	Static	0.361	0.108
	Dynamic	0.432	0.051
Height LLA	Static	0.255	0.265
	Dynamic	.519*	0.016
Area MLA	Static	.471*	0.031
	Dynamic	.439*	0.047
Area LLA	Static	0.308	0.174
	Dynamic	0.41	0.065

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