Development of the dynamic analysis method of the foot deformation and strain distribution during gait

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Summary

In this study, the method to evaluate the relationship between foot deformation and the mechanical function was proposed. The foot shape was measured using six depth sensors. To obtained foot surface data, the original foot shape of a subject was deformed with morphing technique and matched in a position and orientation three-dimensionally. The strain distribution on the foot surface during gait were calculated from the deformed foot shape. The strain distribution showed a similar tendency to the previous reports. Therefore, the proposed method could be a useful and convenient tool to evaluate the foot deformation during movement.

Introduction

In bipedal human gait, the foot shows complicated deformation three-dimensionally to absorb large impact force on a foot contact or to apply propulsive force to ground. The foot deformation is based on the mechanism of arches of the foot. To understand quantitative detail distribution of the foot deformation during gait is helpful to improve diagnosis and treatment such as foot deformity. Ito et al [1] measured the foot shape during gait using three-dimensional digital image correlation technique, though the technique requires the foot to be painted with speckle patterns.

In this study, we proposed a new dynamic measurement method to obtain the whole foot shape during movements including gait and sports maneuvers. This method uses some depth sensors and shape morphing technique, and then allows us to analyze foot deformation and strain distribution.

Methods

In this study, Azure Kinect DK (Microsoft Corp.) and a force plate (FP4060, Bertec) were used to measure foot shape and ground reaction force during gait respectively. Three healthy adult participants were asked to stand static upright to measure right foot shape applied with no body weight (Reference shape). Then, they asked to walk at a speed from 4 to 5 km/h. The foot shape during gait was measured when the right foot was placed on the canter of the force plate (Dynamic measurement).

For each subject, the Reference shape was deformed to dynamic shapes of the foot using a thin-plate spline method [2] as a morphing technique (Foot morphing). In the morphing, control points to deform the Reference shape were decided to reduce surface distances between the Reference shape and the dynamic shapes using a Levenberg-Marquardt method that is a numerical optimization. The control points in this study were arranged to surround the Reference shape in a grid pattern. Thus, in this study, not only the dorsolateral surface of the during gait was evaluated in the foot surface including forefoot and sole of the foot.

Results and Discussion

Figure 1 shows a Dynamic measurement, a Foot morphing and a compression/contraction strain along vertical axis on the foot surface during the stance phase of gait (Strain visualization). Contraction strain occurred on the dorsolateral aspect in the heel strike and on the outer lateral aspect of midfoot in the toe off. This strain distribution was similar to the reports using a digital image correlation technique [1]. This means that the proposed method could be adequate to evaluate the foot deformation and strain distribution.

Also, through the stance phase of a level gait, a compressive strain was shown in the forefoot. This should be caused by dorsiflexion in the heel strike, by the stepping of the forefoot during mid-stance phase, and kicking motion during late stance phase. The proposed method allows us to measure the foot deformation and distribution during gait without markers or painting. Therefore, the method could be useful and convenient tool to understand the foot mechanical function.

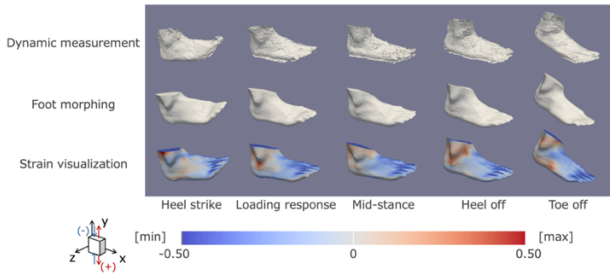

Figure 1: strain distribution on the foot surface during gait

Conclusions

In this study, we proposed a useful and convenient method to evaluate the foot deformation during gait. The obtained surface strain was similar to the previous reports. Therefore, this method could be useful to elucidate the foot deformation during gait and the mechanical function.

References

[1] Ito et al. (2017), Journal of the Mechanical Behavior of Biomedical Materials, **69**: 249-256.
[2] Kiriyama et al. (2014), Journal of Biomechanics, **47**: 302-307.