Mechanisms of Reducing Knee Adduction Moment Using a 3D-Printed Orthotic Shoe with Varied Sole Geometry

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Summary

This study developed 3D-printed orthotic shoes with various sole designs as a non-invasive treatment option for knee osteoarthritis (KOA). Gait tests on 18 healthy subjects revealed that these novel designs, particularly the shoe with a soft hind sole combined with a laterally stiff fore sole, significantly reduced both peaks of knee adduction moment (KAM) compared to conventional control shoes. In addition, different mechanisms were identified in the modulation of each KAM peak when using these shoes, primarily dependent on either the magnitude of the frontal-plane ground reaction force (GRF) or the GRF-knee lever arm. Our findings suggest great potential for implementing 3D printing to fabricate superior custom-designed orthoses for KOA management.

Introduction

Unphysiological KAM is a key factor associated with KOA progression and pain [1-2]. The biomechanical efficacy of LWI in reducing KAM remains inconclusive, highlighting the need for improved foot orthoses. KAMs exhibit two peaks during the stance phase of gait—each corresponding to the kinematics of hindfoot or forefoot—underscoring the need for region-specific sole designs. This study introduces an orthotic shoe concept with 3D-printed outsoles and explores its mechanism in modifying specific KAM-related variables.

Methods

The orthotic shoe comprises a customized leather upper and self-designed shoe sole. Midsole and outsole sketches were created using CAD software, and fabricated using an Artillery 3D printer (Fig. 1). Taking advantage of 3D printing, we adjusted the stiffness and geometry across different sole regions, resulting in three designs: 1) a sole with soft heel (SH); 2) a sole with medially soft heel in lateral shift shape (LS), 3) a sole with medially soft heel in a rocker shape (RS). For the forefoot region, a laterally stiff design was applied, featuring a mediolateral separation along the sole's mid-line.

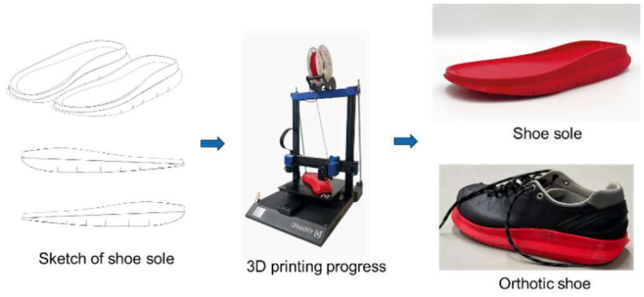

Figure 1: Procedure of 3D printing orthotic shod.

Shod gait tests were performed on 18 subjects to evaluate the influence of orthotic shoes, 5° LWIs, and control shoes on KAM-related variables. Gait data were collected using a 20-camera Vicon motion capture system and three Kistler force plates. Each healthy subject completed three level-walking trials with each orthosis in a randomized order. Raw data were processed and relevant variables computed using Visual3D software. A one-way repeated-measures ANOVA was performed to assess differences in variables across orthoses. Multiple linear regression (MLR) was conducted to identify key variables contributing to KAM variations in each orthosis.

Results and Discussion

ANOVA revealed significant effects of orthotic shoes on the subjects' 1st (P<0.001) and 2nd (P=0.002) peak KAMs. Post-hoc tests indicated that the 1st peak KAM was significantly lower in the LS and SH shoes compared to the control shoes, while the 2nd peak KAM was significantly lower in the RS and SH shoes. MLR analysis revealed different mechanisms in the change in the 1st and 2nd peak KAMs induced by the SH shoe. At the 1st peak, the reduction in KAM was primarily attributed to a decrease in frontal-plane GRF (coefficients β=0.535), corresponding to the use of a soft hind sole. Differently, the primary variable contributing to the reduction of 2nd peak KAM was the shortening of GRF-knee lever arm (β=0.793), due to variation in mediolateral stiffness of the fore sole.

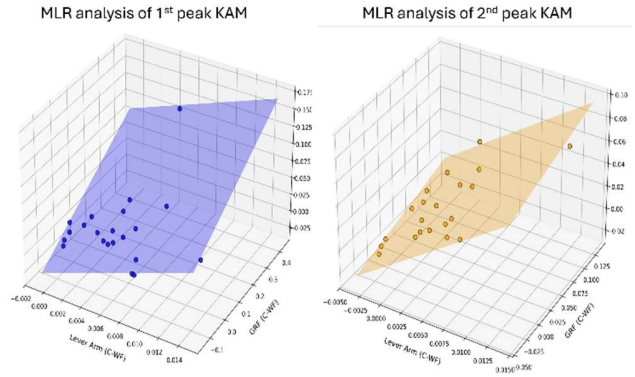

Figure 2: MLR analysis results.

Conclusions

3D-printed shoes reduced both KAM peaks with distinct mechanisms, highlighting their potential to accommodate region-specific foot kinematics of KOA patient during gait.

Acknowledgments

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References

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