Gait Biofeedback Effectively Alters Knee Cartilage Contact Mechanics in ACL-Reconstructed Subjects

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Summary

We used musculoskeletal (MS) models to simulate the stance phase of gait of eight subjects with an anterior cruciate ligament-reconstruction (ACLR) walking normally and cued by visual biofeedback to increase first peak vertical ground reaction force (vGRF) by, on average, 12%. Biofeedback increased center of pressure (CoP) excursion for the medial and lateral tibial compartments ($p < 0.05$). CoP excursion was smaller for the lateral compartment compared to the medial compartment when walking with biofeedback ($p < 0.05$), explaining larger peak cumulative contact pressure values ($p < 0.05$). In conclusion, visual biofeedback elicited a better distribution of stance phase loading across larger portions of cartilage tissue in walking. This could be beneficial for restoring cartilage stimuli to values before the ACL injury.

Introduction

ACLR knees are at a higher risk of developing post-traumatic knee osteoarthritis (PTOA) compared to uninjured knees. Biomechanics of ACLR patients differ from healthy controls, causing abnormal tissue stress and possibly subsequent cartilage degeneration [1]. Visual biofeedback strategies have been successfully implemented in ACLR patients to increase stance phase vGRF to match uninjured controls [2]. Subsequently, biofeedback elicited healthier knee joint contact force profiles and peak knee flexion compared to habitual walking in patients. However, the accumulated effect of these changes at the cartilage tissue level is unknown. In this study, we investigated knee joint contact pressure data estimated from personalized MS models to assess the cartilage dynamics history during the stance phase of walking.

Methods

On separate days, motion capture and treadmill GRF data from eight ACLR subjects (mass: 76 ± 8 kg) were collected for 30 minutes each of: (i) habitual walking and (ii) biofeedback-cued walking (BF), the latter increasing the first peak of the vGRF during the stance phase by ~12% compared to habitual walking (Fig. 1A). MRIs served to create patient-specific 12-degree-of-freedom knee MS models in OpenSim, in which cartilage contact surfaces and ligament insertion points were personalized [3]. Contact pressure results were used for determining two measures of cartilage contact dynamics during walking. We calculated CoP excursion as the distance traveled by the CoP over the contacting cartilages during the stance phase, measured in millimeters (mm). The cumulated contact pressure (CP) consisted of the time integrative of contact pressure over the cartilage surfaces, measured in megapascals-second (MPa-s).

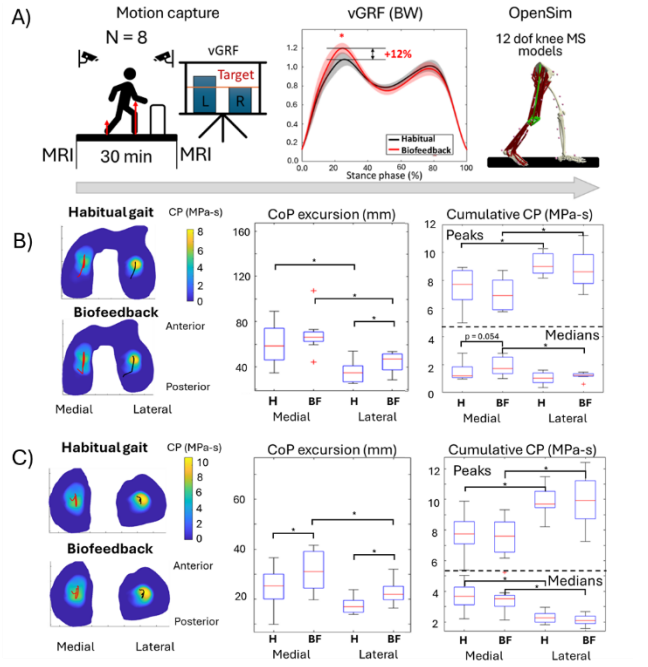

Figure 1: (A) Methods. CoP excursion and cumulative contact pressure in femur (B) and tibia (C) for habitual (H) and biofeedback (BF) conditions. Fringe plots show a typical subject. *$p < 0.05$.

Results and Discussion

CoP excursions increased for BF compared to habitual walking (Fig. 1B-C) despite stance phase durations being indistinguishable (Habitual: 0.68 ± 0.05 s, BF: 0.67 ± 0.07 s). Moreover, peak cumulative CPs were higher for the lateral compartment than the medial compartment for both conditions, possibly due to relatively smaller CoP excursions between the femoral and tibial articulating surfaces. In future research, we will use pre- and post-walking MRIs to calculate residual compressive strains and validate region-specific variation in cumulative CP between walking conditions. Furthermore, we will use finite element analysis including menisci and biphasic fibril-reinforced cartilage formulations [3] to model the effect of BF at the tissue constituent level.

Conclusions

Increasing the first load peak of the vGRF of the stance phase in ACLR patients mechanically stimulated wider regions of articular cartilage compared to habitual walking, potentially normalizing tissue loading similar to uninjured individuals in order to delay PTOA onset and progression.

References

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