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REAL-TIME MODEL-BASED GAIT RETRAINING FOR KNEE OSTEOARTHRITIS REHABILITATION

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INTRODUCTION

According to the Arthritis Foundation, 66 million Americans (or nearly 1 in 3 adults) currently suffer from arthritis, with osteoarthritis (OA) being the most common form, and the knee being the joint most commonly affected. Despite the need for early treatment, few clinical interventions slow the progression of knee OA. Since articular cartilage is responsive to the amount of joint loading, reducing compressive loads in the diseased compartment may slow the rate of cartilage breakdown. Because medial compartment load cannot be measured non-invasively *in vivo*, an external measure to quantify the desired load reduction has been sought. The best candidate found thus far is the external knee adduction moment during gait [1]. This moment exhibits two peaks during the gait cycle, one during early stance phase and the other during late stance. A high peak knee adduction moment has been correlated with increased disease severity [2] and an increased rate of disease progression [3].

Gait modifications are a non invasive treatment option for decreasing the peak knee adduction moment. To date, several gait modifications have been shown to reduce the peak adduction moment in patients with medial knee OA. However, it has been difficult to identify clinically realistic gait modifications that will reduce the first peak or both peaks to an extent comparable to high tibial osteotomy surgery. The goal of this preliminary study was to evaluate whether gait retraining with real-time feedback can facilitate learning a new gait pattern that reduces the peak knee adduction moment. Customized feedback targets for shank position and orientation were generated by a patient-specific computational gait model. Such "biofeedback" allows patients to make immediate corrections to their performance and likely facilitates initial motor learning [4].

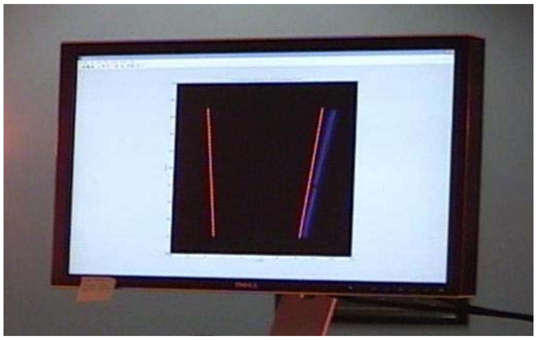

Fig. 1: Example of the customized real-time feedback display.

METHODS

For this preliminary study, one patient (female, age 70, height 1.72 m, weight 72 kg) with medial compartment knee OA was recruited. Institutional review board approval and written informed consent were obtained. During a baseline test session, video motion (Motion Analysis Corporation, Santa Rosa, CA) and ground reaction (AMTI, Watertown, MA) data were collected while the patient performed five gait trials at a self-selected speed. These data along with isolated joint motion trials were used to create a dynamic, patient-specific, full-body gait model using previously published methods [5]. A dynamic gait optimization was then performed to predict new leg kinematics that would minimize the peak knee adduction moment in the affected leg. The optimization predicted a modified walking pattern that moved the knee toward the midline of the body (i.e., knee medialization) by slightly increasing hip internal rotation and knee flexion during stance phase [5,6]. The subject participated in 8 gait retraining sessions on a treadmill, with each session lasting 30

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minutes. Target knee and ankle positions in the frontal plane were taken from the optimization results and displayed as orange bars on a computer screen in front of the treadmill, and target stance leg knee and ankle locations were displayed in real-time as similar blue bars (Fig. 1). The subject was instructed to align the blue bars with the orange bars by changing leg motion as predicted by the gait optimization. Knee and ankle locations were calculated using custom software that accessed real-time shank marker data provided by an eight-camera EVaRT System. The real-time display was generated using Matlab (The Mathworks, Natick, MA).

Changes from baseline were evaluated by collecting gait data at four time points: following 4 retraining sessions (2 Weeks Post), following 8 retraining sessions (4 Weeks Post), and 1 month after completing training both before "(8 Weeks Pre) and after (8 Weeks Post) after a 15 minute gait retraining "refresher."

RESULTS

Both peaks of the subject's knee adduction moment were significantly reduced from baseline at all measured time points (Fig. 2). On average, the first peak was reduced by approximately 10% and the second peak by approximately 20% (Table 1). The largest reductions occurred after the first four training sessions, with the first peak in particular increasing slightly at subsequent measurement points. The reductions achieved for both peaks were smaller than those predicted by the patient-specific gait optimization, consistent with the patient being unable to reach the optimal target in the real-time feedback display (Fig. 3, right side for affected leg).

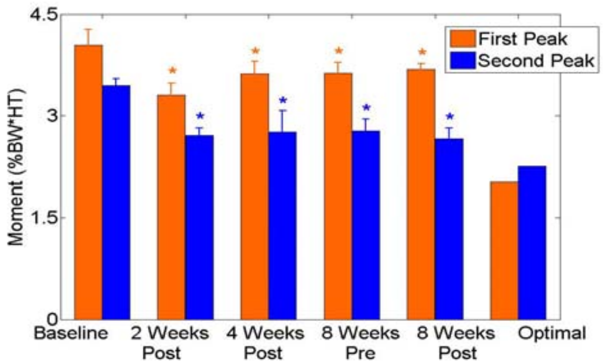

Fig. 2: First and second adduction moment peaks at various time points during the study. Stars (*) indicate statistically significant changes compared to baseline.

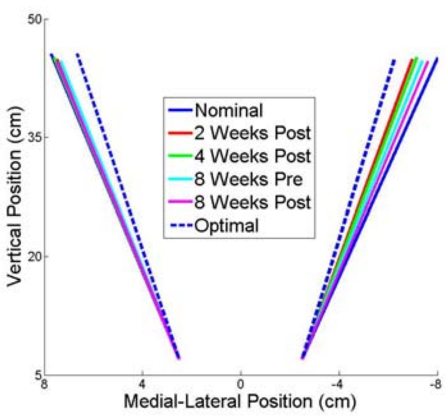

Fig. 3: Optimized knee and ankle center locations in the frontal plane at the first knee adduction moment peak.

Time Point	First Peak	Second Peak
2 Weeks Post	16.0 ± 7.4	21.5 ± 3.3
4 Weeks Post	8.1 ± 7.7	19.8 ± 7.9
8 Weeks Pre	11.0 ± 6.3	18.9 ± 4.9
8 Weeks Post	9.1 ± 5.5	21.8 ± 4.6

Table 1: Percent reduction (mean ± std) in peak knee adduction moment at various time points during the study.

DISCUSSION

This study successfully combined customized feedback targets with real-time motion data to create a novel gait retraining approach for knee osteoarthritis rehabilitation. The feedback targets were generated via dynamic optimization of a patient-specific computational gait model. Though the achieved reductions were less than those predicted by the patient-specific computational model, the approach still produced lasting changes that did not depend on receiving "refresher" training. Thus, while the reductions were small, they were well maintained by the patient.

The relationship between knee medialization and the reduction in the first adduction moment peak was strong for this subject (compare reductions shown in Fig. 2 and extent of knee medialization shown in Fig. 3, right side). The subject matched the feedback targets the best 2 weeks into gait retraining, which was also when the subject achieved the largest reductions in the first peak. In physical terms, decreasing the medial-lateral distance between knee and ankle center will decrease the moment arm of the ground reaction force vector about the knee center, resulting in a decreased adduction moment.

Though this preliminary evaluation was generally successful, future improvements to the feedback display may be necessary. The current bars make the patient try to match two quantities – knee and ankle center location – simultaneously during stance phase. Determining ways to combine these quantities into a single quantity may improve the learning process. It may also be better to project the knee and ankle center onto a plane rotated with the shank in the sagittal plane to increase the correlation between knee medialization changes and changes in the knee adduction moment peaks.

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