Decreasing Knee Joint Contact Loads via Toe-In Gait for Patients with Knee Osteoarthritis

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INTRODUCTION

Knee osteoarthritis (OA) is a painful and prevalent chronic condition causing physical disability affecting nearly one in five adults over the age of 45 [1]. Excessive knee loading has long been thought to be a major contributor to articular cartilage degeneration associated with OA progression and it has been found that patients with OA exhibit increased knee joint loads during gait [2], which may potentially be mitigated with gait modification. Toe-in gait modification has been shown to reduce the first peak of the net external knee adduction moment (KAM) in patients with symptomatic medial compartment knee OA [1, 3], but the effect of toe-in gait on muscle forces affecting knee loads is unknown. Investigating knee joint contact loads, specifically the internal forces and moments the joint structure carries, under toe-in gait conditions may better characterize this gait modification in terms of creating targeted intervention strategies.

In this study, we aimed to determine the effects of toe-in gait modification on the knee joint contact loads in individuals with medial compartment knee OA. We hypothesized that toe-in gait reduces the relative medial knee contact load, the load directly related to the unbalanced bone-on-bone forces experienced by the medial and lateral knee joint compartments, in subjects with medial knee OA.

METHODS

Eight subjects (4 female, 6 male; 60±13 yrs.; 171±9 cm; 79±20 kg; 26.6±4.7 kg/m^2 BMI) with self-reported knee pain and radiographic evidence of medial compartment knee OA walked with normal and toe-in gait. Two-hundred forty subject-specific muscle-actuated dynamic simulations (8 subjects times 10 steps for normal gait at baseline, 10 steps for toe-in gait after 6-week training, and 10 steps for toe-in gait at one month follow-up) were created to estimate knee joint contact loads for all subjects. To determine the changes in knee joint contact loads, the tibiofemoral bone-on-bone joint contact forces and moments (collectively, contact loads) were computed using the Joint Reaction Analysis tool in OpenSim [4]. This analysis yields 6 separate contact loads at each joint, including anterior shear, superior compression, and lateral shear forces and moments about these force directions (in anatomical planes), including relative medial knee contact (frontal), internal rotation (transverse), and extension (sagittal). Contact load values were compared at the percent of stance where the first peak external KAM occurred, which is where toe-in gait modification has the largest effect. We evaluated our hypothesis regarding tibiofemoral contact load changes as a result of toe-in gait modification by conducting a paired Student's *t*-test at the 0.01 significance level.

RESULTS AND DISCUSSION

There were a number of differences and similarities in tibiofemoral joint contact loads with toe-in gait modification in subjects with knee OA. At 27% of stance, where the first peak external KAM occurs, the relative medial knee contact load (note, this is different from the net KAM from inverse dynamics) on the tibiofemoral joint was significantly lower ($p<0.01$), on average, when subjects walked with a toe-in gait compared to normal gait (Figure 1a). The relative medial knee contact load during normal gait (3.0±0.7% BW*HT) was reduced by approximately 18.7% after toe-in gait modification (2.5±0.6% BW*HT). While the relative medial knee contact load was reduced after toe-in gait modification, there were no significant differences in the compressive and shear joint contact forces ($p>0.17$) nor extension and internal rotation contact moments ($p>0.07$) on the tibiofemoral joint after toe-in gait retraining as compared to normal gait. These results were retained after one month following the final gait retraining session. At the one-month follow-up

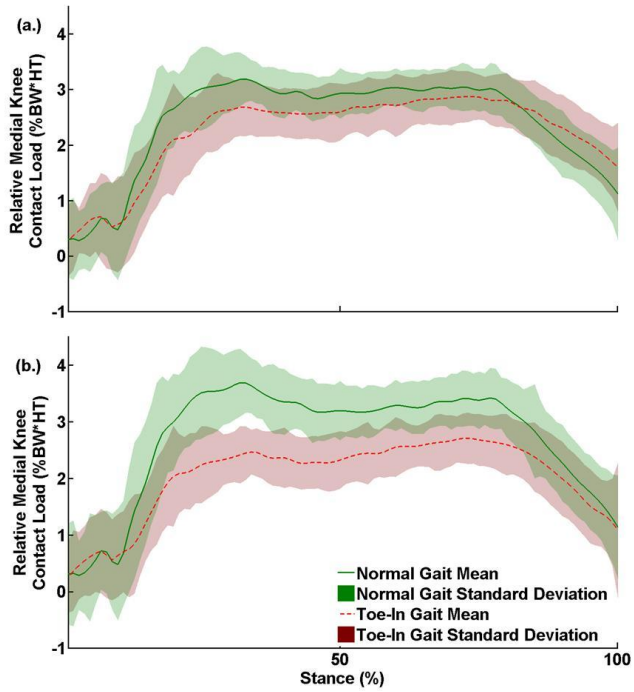

Figure 1: All subjects showed (a.) a 18.7% ($p<0.01$) decrease in the relative medial knee contact load, at 27% of stance, where the first peak external KAM occurs, for toe-in gait compared to normal gait following a 6-week training schedule, and (b.) a 25.3% decrease ($p<0.01$) in the relative medial knee contact load at the same location in stance for toe-in gait at the one-month follow-up.

session, the relative medial knee contact load on the tibiofemoral joint was significantly lower ($p<0.01$), on average (Figure 1b). The relative medial knee contact load during normal gait (3.0±0.7% BW*HT) was reduced by approximately 25.3% after toe-in gait modification (2.3±0.6% BW*HT). Again, there were no significant differences in the compressive and shear joint contact forces ($p>0.05$) nor extension and internal rotation contact moments ($p>0.08$) on the tibiofemoral joint after one month following toe-in gait retraining as compared to normal gait.

It is important to note that the values reported in the current study represent the whole knee joint contact loads, rather than narrowing in on the medial compartment where subjects exhibit evidence of knee OA. The relative medial knee contact load relates to the compression of the medial compartment causing the bone-on-bone contact characteristic leading to OA, thus finding a reduction in this contact load shows an improvement for patients with medial knee OA, especially with the results being retained in all subject**s** after one month. While we found a uniform decrease across subjects for the relative medial knee contact load, individual subjects saw varying amounts of changes with some improving more than others. It is possible that the unique changes in muscle forces following toe-in gait results in the varying degrees of change in knee joint contact loads seen in this study [5]. The uniform improvement in the relative medial knee contact load following non-uniform self-selected muscle patterns shows the efficacy of toe-in gait to improve overall knee function for individuals with knee OA.

CONCLUSIONS

This study examined changes in knee joint contact loads due to a toe-in gait modification as compared to normal gait. When using toe-in gait, all subjects uniformly decreased the relative medial knee contact load, while adopting different muscle force modifications [5], and retained those results after one month. It will be useful in the future to identify significant features of gait that decrease joint loads to clarify the potential of gait modification for all patients with knee OA. Finally, the results of this study add to an increasing body of knowledge suggesting a need for further research to determine optimized subject-specific gait modification strategies for knee osteoarthritis.

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