KNEE JOINT FORCES AND MOMENTS IN BELOW-KNEE AMPUTEES ACROSS INCREASING STEADY-STATE WALKING SPEEDS

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INTRODUCTION

Unilateral below-knee amputees experience many gait abnormalities relative to non-amputees that often lead to pain and joint disorders [1]. Joint pain is most frequently reported in the intact leg knee, and long term prosthetic use is associated with increased prevalence of developing osteoarthritis [1]. However, the mechanism causing intact knee osteoarthritis in amputees remains unclear. Studies analyzing sagittal plane quantities have identified increased intact leg loading relative to the residual leg, leading some to suggest that the reduced residual leg loads are a protective mechanism against developing residual limb pain. However, protecting the residual leg may lead to long-term detrimental consequences in the intact leg.

Studies analyzing knee joint loading have shown an increased knee abduction (internal) moment is associated with higher medial compartment forces and joint degradation, which is proportional to osteoarthritis severity [2]. But, low severity patients have not shown differences in knee loads compared to control subjects. In amputee gait, research has shown the intact knee abduction moment is greater than the residual leg at self-selected walking speeds and concluded the higher loads may be the cause of joint degradation, although there was no increase in the intact knee abduction moment compared to non-amputee control subjects [3]. Thus, it remains unclear whether the increased intact knee abduction moment causes osteoarthritis in amputees, or if it is an adaptation as a result of the disease.

To date, no study has examined three-dimensional intersegmental joint forces and moments in the intact and residual knees over a range of walking speeds in subjects without a history of osteoarthritis. The influence of walking speed on knee joint forces and moments would be important to investigate since it has been shown to influence muscle activity and joint work in amputees [4]. Thus, the purpose of this study was to examine three-dimensional joint forces and moments across a range of walking speeds to gain insight into potential causes of intact knee osteoarthritis in asymptomatic amputees. We tested four hypotheses at each walking speed: (1) net intersegmental joint forces and (2) moments of the intact knee will be greater than non-amputee control subjects, and (3) net intersegmental joint forces and (4) moments of the intact knee of amputees will be greater than in the residual knee.

METHODS

We tested 14 unilateral, below-knee amputees (11 traumatic, 3 vascular; 45 ± 9 years) and 10 non-amputee control subjects (33 ± 12 years), who were free of any known musculoskeletal disorders and pain. Post-amputation time was 6 ± 3 years. Each amputee used their own prosthesis. Subjects walked along a 10-m walkway at four randomly-ordered, steady-state speeds of 0.6, 0.9, 1.2, and 1.5 (±0.06) m/s, while kinematic data were measured using a motion capture system (Vicon, Oxford Metrics, Inc.) and ground reaction force data were measured using four embedded force plates (Advanced Mechanical Technology, Inc.). Repeated trials were collected until five force plate contacts per foot were measured at each speed.

An inverse dynamics analysis was performed to calculate the intersegmental joint forces and moments using Visual3D (C-Motion, Inc.), which were expressed in the local orthogonal femoral frame. Kinematic and GRF data were low-pass filtered. Joint forces and moments were normalized by the body mass of each subject. A total of nine knee intersegmental moment and force impulses (knee extension, flexion, abduction, internal rotation, and external rotation moment impulses and lateral, anterior, posterior, and axial force impulses) were computed over stance. For each impulse, two (intact to control knee, intact to residual knee), two-factor, repeated-measures ANOVAs were computed to compare quantities across leg (intact, residual), group (amputee, control) and speed. Pairwise comparisons were made when significant differences were detected using a Bonferroni adjustment ($p \leq 0.05$).

RESULTS AND DISCUSSION

The hypothesis that intact knee moments would be greater than the control subjects was not supported. In fact, knee abduction moment impulse was significantly smaller in the intact knee compared to control subjects at 0.6 and 0.9 m/s ($p \leq 0.031$, Fig. 1). These results are in contrast to previous work that found an increased peak intact knee abduction moment relative to the residual knee [3]. Royer et al. [3] tested patients free from osteoarthritis and of a similar age (42 ± 11 years) to our amputee subjects (45 ± 9 years). However, post-amputation time (17 ± 11) was substantially larger than in our study (6 ± 3 years). Thus, their larger intact knee abduction moment may be an adaptation that occurs with longer prosthesis use or is possibly in response to the initial stages of disease.

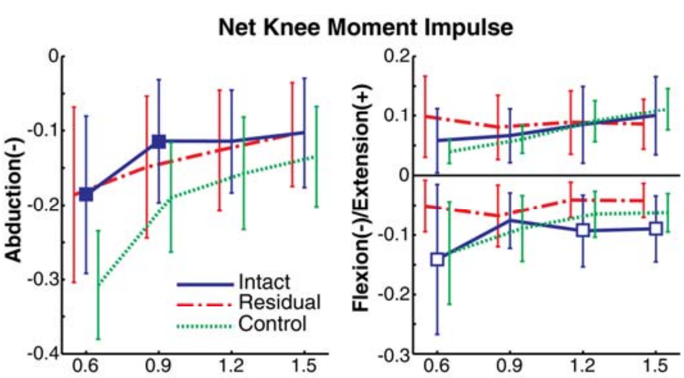

Fig. 1: Mean ± standard deviation moment impulses (N*m*s/kg) of the intact, residual and control knees. Significant intact differences relative to control (■) and residual (□) knees are indicated.

The hypothesis that intact knee moments would be greater than the residual knee was supported with the knee flexion moment impulse at 0.6, 1.2 and 1.5 m/s ($p \leq 0.009$, Fig. 1), and knee external rotation moment impulse at all speeds ($p \leq 0.041$). Also, knee extension moment impulse did not significantly change as speed increased in the residual knee, while it increased in the intact knee ($p \leq 0.043$, Fig. 1). The bilateral asymmetry in these quantities may be a contributing factor to the development of intact knee osteoarthritis.

There were no significant differences found in intersegmental force impulses between legs. The absence of a difference in force impulses does not rule out that amputees do not experience larger intact knee contact forces. Intersegmental joint forces underestimate joint contact forces because they do not account for muscle co-contraction or compressive forces due to ligaments [5]. Modeling studies quantifying the contributions of muscles and external loads to joint contact forces have provided insight into joint loading of non-amputees and future work is needed to analyze amputee gait.

Previous studies have shown amputees experience higher metabolic cost and slower self-selected walking speeds relative to non-amputees. An interesting finding in the present study was that the highest degree of symmetry between residual and intact knee loads occurred at 0.9 m/s. The lower self-selected walking speed by amputees [e.g., 3] may be influenced by the improved load symmetry that occurs at slower speeds.

CONCLUSIONS

Analyzing intersegmental joint forces and moments was inconclusive in identifying potential causes of intact knee osteoarthritis since no intact knee quantities were greater than the control knees. However, bilateral loading asymmetry between intact and residual knees was shown to exist, which may lead to joint degradation over time.

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