Does Muscle Force Production During Sit-To-Stand Change Following a Primary Total Knee Arthroplasty?

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INTRODUCTION: Rising from a chair is a common dynamic task that is essential for independent living and mobility.[1] The sit-to-stand (STS) task is particularly challenging for individuals with knee osteoarthritis (KOA), in which they typically demonstrate slower STS speeds and compensatory movement strategies that may be associated with the development of subsequent joint diseases.[2] A goal of total knee arthroplasty (TKA) is to improve function so that these individuals can perform activities of daily living, like the STS, but previous experimental studies have not been able to demonstrate improvements in kinematic, kinetic, or neuromuscular strategies during STS after a primary TKA.[2,3] However, traditional experimental techniques and inverse dynamics approaches alone are not able to provide insight into the force production of individual muscles. Musculoskeletal simulations extend experimental observations to investigate the role of individual muscle forces produced during dynamic tasks, like STS.[5] Identifying whether muscle force production, interlimb muscle force asymmetry, or lower extremity kinematics change following a primary TKA will inform rehabilitation programs by providing additional insights into the persistent functional deficits often observed following TKA. We hypothesized that pre- and post-TKA comparisons would yield differences in (I) forces produced by the lower extremity muscles, (II) interlimb muscle force asymmetry, or (III) sagittal plane hip, knee, and ankle kinematics.

METHODS: Seven individuals with medial compartment KOA who were scheduled to undergo a primary posterior-stabilizing TKA, a subset of the data presented previously,[6,7] provided written informed consent for enrolling in an Ohio State IRB-approved study. Each participant completed a five-times STS test,[8] during which kinematic, kinetic, and electromyographic (EMG) data were collected approximately 1 month prior to surgery and 6 months after surgery. One representative chair rise was analyzed for each participant at each time point (pre- and post-TKA). A modified Bosch et al. musculoskeletal model[9] was scaled to the anthropometrics of each subject[5] to conduct dynamic simulations in OpenSim[5] for each STS cycle. Computed muscle control (CMC)[10] with EMG-constrained muscle excitations[11] resolved net joint torques into individual muscle forces during the STS cycle. We focused our analysis to the sagittal plane for the following muscles: gluteus maximus, iliacus, psoas, vastus lateralis, rectus femoris, vastus medialis, vastus intermedius, biceps femoris, semitendinosus, semimembranosus, soleus, medial gastrocnemius, lateral gastrocnemius, and tibialis anterior. Peak muscle forces, interlimb percent difference in peak muscle forces[12] ("interlimb asymmetry"), and peak sagittal plane hip, knee, and ankle (HKA) angles were found within each of the 3 phases of the STS cycle.[13] Initial seated position (HKA angles at 0% of STS cycle) was included as an additional kinematic measure. Peak muscle forces of the involved limb, interlimb asymmetry, peak HKA kinematics, and initial HKA kinematics were compared between time points within the same individual using separate general linear models. Tukey post hoc pairwise comparisons were used to investigate peak muscle forces, interlimb asymmetry, and HKA kinematics as appropriate.

RESULTS: For Hypothesis I, across STS cycle phases, there was no significant difference in peak muscle forces generated in the same muscle before or after surgery ($P = 0.117$; Fig 1). For Hypothesis II, across STS cycle phases, there was no significant difference in interlimb asymmetry between time points ($P = 0.619$). For Hypothesis III, across STS cycle phases, there were no significant differences in peak hip ($P = 0.062$) and peak knee angles ($P = 0.087$) between time points. There were no significant differences in initial knee ($P = 0.425$) and initial ankle angle ($P = 0.102$) between time points. However, there were significant differences in peak ankle angles and initial hip angle before and after surgery (all $P < 0.02$). Individuals demonstrated more posterior foot placement before surgery, which is reflected in the larger peak dorsiflexion angles before surgery. For example, during Phase 1, individuals demonstrated significantly more dorsiflexion before surgery (Before: 32.1 ± 4.4°, After: 27.6 ± 2.7°; $P = 0.013$; Fig 2). Prior to surgery, individuals demonstrated significantly less initial forward trunk lean, which is reflected in the decreased initial hip flexion angle (Before: 63.5 ± 9.3°, After: 71.8 ± 10.3°; $P = 0.015$; Fig 2).

DISCUSSION: Our analyses did not identify significant differences for Hypotheses I and II, and they partially supported Hypothesis III that following a primary TKA, there were significant changes in some kinematic parameters (peak ankle angles, initial hip angle) during STS. Muscle force production patterns at both time points qualitatively differ from those of healthy, young adults, who exhibit higher gluteus maximus forces, compared to other lower extremity muscle forces.[12] In TKA patients, higher forces in the soleus may compensate for a gluteus maximus muscle force deficit both before and after surgery. Differences in foot placement and forward trunk lean before and after a TKA represent distinct kinematic modifications that both leverage the use of momentum rather than muscle force production to drive the motion.[14] Our results suggest that persistent functional deficits in performing STS following the first six months of recovery from a TKA may be explained by continued compensatory strategies that leverage momentum rather than muscle force production, particularly in the gluteus maximus. Future work should explore how postoperative STS performance is influenced by muscle strength and the ability of muscles to contribute to the movement.

SIGNIFICANCE/CLINICAL RELEVANCE: These findings demonstrate that muscle force production when rising from a chair does not change within six months following a primary TKA. Our work suggests a need for focusing rehabilitation efforts on changing postoperative muscle force production, particularly for the gluteal muscles, as well as kinematic retraining for reducing use of momentum during STS (by modifying foot placement and trunk motion) during this early recovery period.

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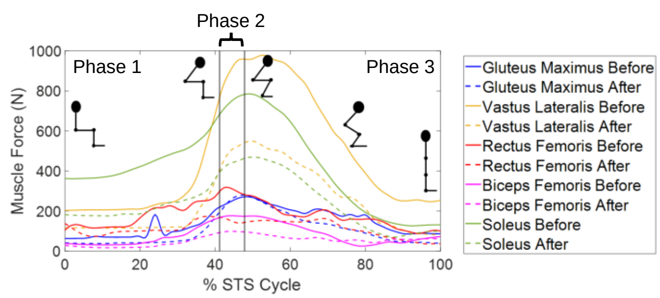

Figure 1. Average muscle forces from representative muscles in the involved limb before and after TKA over the STS cycle.

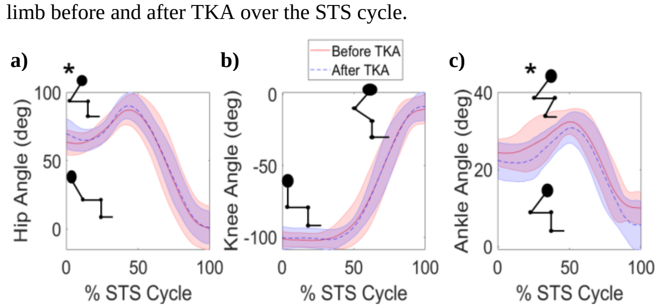

Figure 2. Average hip (a), knee (b), and ankle (c) angles for the involved limb before and after TKA over the STS cycle. Symbols (*) indicate significant difference before and after TKA.