# Sensitivity of Pediatric Knee Kinematics to Anterior Cruciate Ligament Reconstruction Parameters

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INTRODUCTION: Optimizing anterior cruciate ligament reconstruction (ACLR) surgery is of urgent need specifically in the pediatric population as sub-optimal surgery can alter knee biomechanics, leading to joint instability, and re-rupture [1]. Orthopedic surgeons have numerous options for graft insertion, pre-tension, type, and other parameters which may affect post-operative knee biomechanics. Finite element (FE) simulations can provide insight into consequences of different surgical choices on post-operative knee biomechanics [2]. We developed a sequentially linked subject-specific neuromusculoskeletal (NMSK)-FE model of two pediatric knees for pre-surgery planning. Here, we assessed the sensitivity of post-operative knee kinematics to graft type, diameter, femoral tunnel location, and pre-tension.

METHODS: The lower-limb geometry from two participants (mean age 14.0±2.6 years, mass 51.1±10.5 kg) were acquired using magnetic resonance imaging. For each participant, 135 subject-specific FE knee models were created, each consisting of a surgically plausible combination of three variations for graft type (i.e., gracilis, semitendinosus, and patellar tendon), diameter (i.e., 6, 8, 9 mm), and pre-tension (i.e., 0, 40, 100 N), and five variations for femoral graft location (±5 mm deviation from native footprint of ACL toward medial, lateral, anterior, and posterior directions). Three-dimensional motion (Vicon Motion Systems Ltd, UK), ground reaction forces (AMTI, MA, USA), and 10 lower-limb muscle electromyograms (EMG) were acquired from each participant during walking at a self-selected pace. The subject-specific FE boundary conditions, and loading were estimated using OpenSim and calibrated EMG-assisted model, respectively. Knee flexion angle, knee abduction-adduction and internal-external rotation moments, as well as tibiofemoral and patellofemoral joint contact forces were used to drive FE models [2]. Then, a multi-input multi-output time-varying sensitivity analysis was used to assess sensitivity of secondary knee kinematics (i.e., anteroposterior, and mediolateral femoral translations, as well as abduction-adduction and internal-external femoral rotations) to graft size, pre-tension, type, and femoral tunnel location through Sobol' indices at five instances across the stance phase of gait.

RESULTS SECTION: Sensitivity of secondary knee kinematics to ACLR parameters varies across stance (Figure 1). At initial foot contact, first order effects of graft parameters on secondary knee kinematics were largest. As the participants progressed through stance, second order effects (i.e., parameter interactions) on secondary knee kinematics increased in importance. Notably, graft type (i.e., gracilis, semitendinosus, and patellar tendon) had greatest first-order effects on secondary kinematics compared to other surgical parameters at certain time points for both participants. Graft location had the weakest effect on secondary kinematics, particularly evident for the first participant. Knee rotations emerged as the most sensitive of the secondary kinematics to variations in surgical parameters, specifically for the first participant (Figure 1A).

DISCUSSION: We used two personalized FE models of the pediatric ACLR knee to assess sensitivity of secondary knee kinematics to key surgical parameters. We found the effects of surgical parameters on secondary kinematics varied across the stance phase of gait, meaning no generalized conclusion about the importance of surgical parameters to knee function could be made. Further, results demonstrated geometry-specific differences between the two participants, meaning model selection influenced sensitivity analysis further impeding any general conclusions about the sensitivity of secondary kinematics to ACLR parameters. This study is the first comprehensive and practical sensitivity study examining the influence of pediatric ACLR surgical parameters on knee kinematics. We will extend our analyses to encompass additional subjects with substantially different knee geometries and will assess tissue-level mechanics.

SIGNIFICANCE/CLINICAL RELEVANCE: Our study provides the first comprehensive sensitivity analysis of pediatric knee kinematics to key surgical parameters. Sensitivity analysis is critical to informing the relevance of surgical parameters to post-operative function in a clinical indication, i.e., pediatric ACLR, that is increasing in prevalence. The research holds promise to enhance clinical decision-making and optimize pediatric ACLR.

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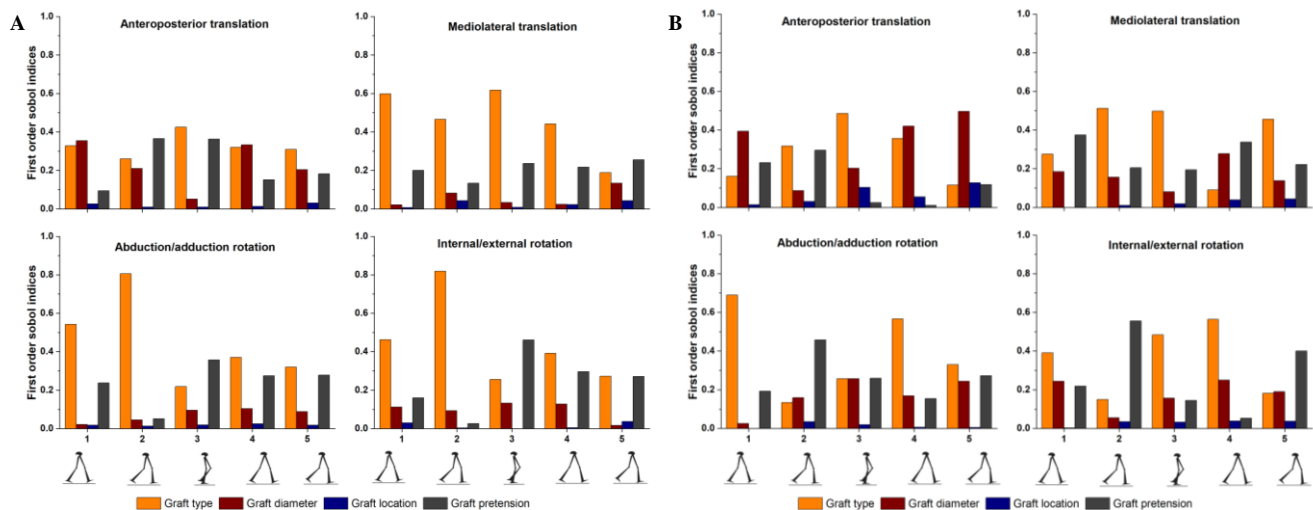
Figure 1. Multi-input multi-output time-varying sensitivity analysis of four key parameters of anterior cruciate ligament reconstruction surgery on secondary kinematics of the pediatric knee. Sensitivity was quantified by Sobol' indices for 5 time points across stance for two (i.e., A, B) participants.