Simulating Soft Tissue Releases and their Effects on TKA Mechanics using Forward Dynamics Modeling

Amitkumar M. Mane[1], Chase Maag[1], Richard D. Komistek[2], Stephen E. White[1]
[1]DePuy Synthes, Warsaw, IN, [2]U. of Tennessee, Knoxville, TN
Amane5@its.jnj.com

INTRODUCTION: Clinical outcome of total knee arthroplasty (TKA) relies on multiple factors, such as implant alignment, sizing, soft tissue balancing etc. [1, 2]. Inappropriate soft tissue tension and imbalance, potentially caused due to the implant mal-alignments, have shown to cause post-TKA instability [1, 2]. Intraoperatively, surgeons assess the soft tissue envelope, and if not balanced appropriately, typically ligament releases are performed to achieve desired soft tissue balance. However, these assessments are performed during non-weight bearing passive flexion activity. Insight into how the balanced joint, achieved by ligament releases, perform during weight-bearing activities (ADLs) can shed more light on soft tissue balancing. Thus, objective of this work was two-fold: First, develop a computational modeling methodology to simulate imbalance and later correct it with ligament releases during passive flexion. And second, assess performance of two implant systems during ADLs using corrected configuration obtained in first step.

METHODS: Previously validated forward dynamics model (FDM) was used for this analysis (Fig. 1-a) [3]. The flow-chart of a research method is summarized in Fig. 1-b. First step included the passive flexion assessments using contemporary Cruciate Retaining system with mechanical alignment, referred as Implant-1. A baseline passive flexion activity was simulated from 0-120º with a compressive load of 150N. Later, three mal-alignments were created, and passive flexions were simulated at: Mal-alignment 1- 1º femoral internal mal-rotation, Mal-alignment 2- 1º tibial valgus mal-rotation, and Mal-alignment 3- 2º reduced tibial posterior slope. For corrective actions, in Mal-alignment 1, deep MCL stiffness was reduced by 8% to simulate its release. In Mal-alignment-2, MCL attachment was distalized to simulate its release at the attachment point. In Mal-alignment 3, PCL stiffness was reduced by 8% to simulate its release. Later, to assess effects of mal-alignment and their corresponding corrections, the changes in ligament strains in mal-alignments, and corrected mal-alignments were compared with those observed in baseline passive flexion. Second step was focused on the ADLs. Using Implant-1 and another contemporary TKA system, referred as Implant-2, a DKB, step down (SD) and step up (SU) activities were simulated at the base line configurations (Fig. 1-b). Same three mal-alignments and their corrections from step one above were introduced, and ADLs were simulated in both implants. The ligament strains in corrected mal-alignment configurations during ADLS were compared with those noted during baseline ADL simulations.

RESULTS: Changes in the MCL, LCL and PCL strains, in mal-alignment and corrected mal-alignment configurations relative to the baseline passive flexion are summarized in Fig. 1-c. All three bundles of the MCL experienced increase in their strains up to 3.8% with all three mal-alignments. Whereas the reduced tibial slope increased strain in the posterior-medial PCL bundle by 2.5%. These strains reduced substantially and came close to the baseline strain magnitudes (within ±0.5%) with respective simulated corrections. Changes in ligament strains between baseline ADLs and mal-alignments with corrections are summarized in Fig. 2. In Implant-1, the ligament strains during corrected mal-alignment configurations remained close, within ±1%, to their baseline magnitudes. These magnitudes increased up to 4% for Implant-2. During DKB with corrected mal-alignments, anterior and Oblique MCL, and PCL strains increased up to 1% in Implant-1, and up to 4% in Implant-2. Similar trends were observed during SD and SU activity. Moreover, during SD and SU activity, both Implants experienced increase in the deep MCL strain at all mal-alignments; but during DKB, the implants decrease in its strain.

DISCUSSION: The study demonstrated ability of FDM to simulate clinical scenario where surgeons may detect imbalance (using ligament strains) due to the implant mal-alignment, and later correct it with the ligament releases. The corrective actions implemented for the respective mal-alignments are routinely followed intraoperatively [4]. Increased ligament strains with mal-alignments observed in simulations can be a representative of joint imbalance or 'tightness' experienced intraoperatively. Whereas the reduction in the ligament strains (close to the baseline strains) may represent balanced joint after corrective steps. When post-corrective configurations were used in the ADLs, two implant systems responded differently, with Implant-1 showing smaller changes in ligament strains than those experienced by the Implant-2. Furthermore, type of activity also influenced the ligament response in the post-corrective simulations, such as, reduction in the deep MCL strains in DKB, but increase in SD and SU activity. The observation may relate to patients who experience post-TKA joint tightness during certain activity, such as SD [5]. Previous work have highlighted harmony between the motion and surrounding soft tissues in Implant-1, which may have played a role in smaller strain magnitudes during post-corrective simulations [6, 7]. Recent retrospective analyses have demonstrated accurate implant placement using Robotics and overall lower incidence of soft tissue releases in TKA [8, 9], indicating benefits of accurate implant placement methods in TKA. In summary, the work highlighted effect of soft tissue imbalance on both passive flexion and ADLs.

SIGNIFICANCE/CLINICAL RELEVANCE: The work outlined a methodology to recreate intra-operative clinical soft tissue imbalance, the corrective actions, and their effects during ADLs.

REFERENCES: 1. Deehan *et al.*-2018, 2 Wilson *et al.*-1998, 3. Khasian et al.-2020, 4. Choong *et al.*-2009, 5. Hoffman *et al.*-2011, 6. Mane *et al.*-ORS 2020, 7. List *et al.*-2020, 8. Hunter *et al.*-EFORD 2023, 9. Doan *et al.*-ORS2021.
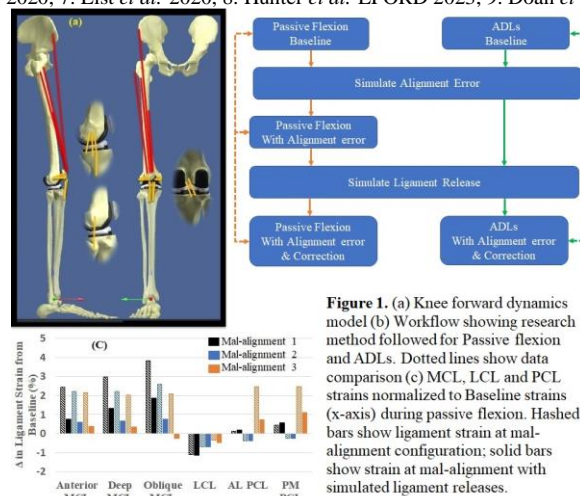
Figure 1. (a) Knee forward dynamics model (b) Workflow showing research method followed for Passive flexion and ADLs. Dotted lines show data comparison (c) MCL, LCL and PCL strains normalized to Baseline strains (x-axis) during passive flexion. Hashed bars show ligament strain at mal-alignment configuration; solid bars show strain at mal-alignment with simulated ligament releases.
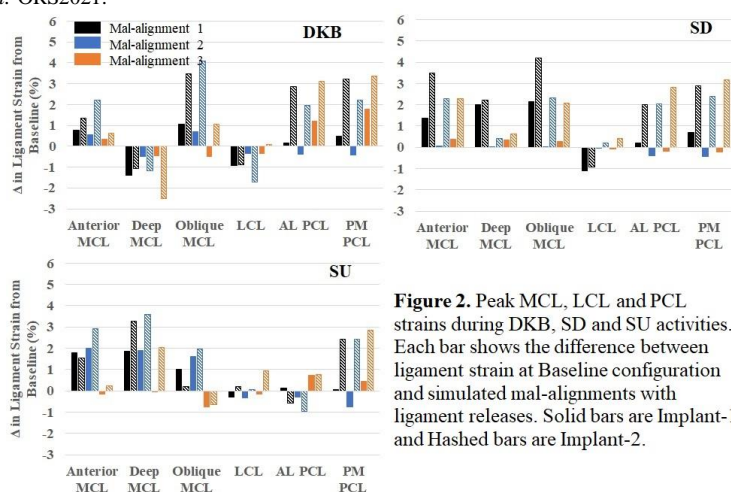
Figure 2. Peak MCL, LCL and PCL strains during DKB, SD and SU activities. Each bar shows the difference between ligament strain at Baseline configuration and simulated mal-alignments with ligament releases. Solid bars are Implant-1 and Hashed bars are Implant-2.