# Impact of surgical, patient, and implant design factors on implant-bone interface micromotions in cementless unicompartmental knee replacement

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INTRODUCTION: Micromotion exceeding 150µm at the implant-bone interface may prevent bone formation and limit fixation after cementless knee arthroplasty [1]. Understanding the critical parameters impacting micromotion is required for optimal implant design, patient selection, and clinical performance. Previous studies commonly use finite element models to estimate tray-bone micromotion and to investigate the micromotion sensitivity of key factors in total knee arthroplasty (TKA) [2]. However, few studies have focused on uni-compartmental knee arthroplasty (UKA). Hence, this study aimed to investigate the influence of the implant-bone alignment parameters, contact friction, and bone properties on interface micromotions in UKA during a series of activities of daily living.

METHODS: A previously validated model predicting tray micromotion in cementless TKA [3] was virtually implanted with cementless UKA prostheses (best-fit size, fixed bearing, prototype, DePuy Synthes), following the manufacturer's surgical technique. Lateral compartment cartilage was reconstructed from the bone surfaces and hex-meshed using a morphing tool (Fig.1). All components were modeled as deformable with appropriate material properties, and the interaction surfaces were modeled with frictional contact except cartilage, which was tied to the bone surfaces. The model was evaluated in ABAQUS/Standard to simulate gait (GT), deep knee bending (DKB), and stair descent (SD) activities. Flexion/extension (FE), anterior/posterior (AP), medial/lateral (ML), and internal/external (IE) degrees of freedom (DoFs) were kinematically driven, and the applied kinematics were derived from *in-vivo* fluoroscopy data for the same size UKA [4]. Superior/inferior (SI) and varus/valgus (VV) DoFs were load controlled, and the applied forces were derived from a previously-developed lower limb model [5]. Based on the initial implant alignments, ten models were developed by perturbing tibial tray-bone alignment (one perturbation at a time) by ±1.0mm translations in AP & ML directions and femoral-bone alignment by ±1.0 & 2.0mm in the ML direction and ±1.0mm in the AP direction. Two additional models were established by altering the coefficient of friction at the implant-bone interface with 0.6 and 1.4 (initial $\mu$=1.0 according to internal experimental data). Another model was created by re-mapping the elastic properties of the bones using an upper-bound elastic-density relationship [6]. For each model in each activity, the peak interface tibial and femoral micromotions, average interface micromotion, and the percentage of the surface area with micromotion less than 50µm were compared to quantify the impact of each factor on the micromotion.

RESULTS: Peak micromotions were consistently found at central aspect of the tray-bone interface (Fig. 2, top). The peak and average femoral micromotions were 92.1µm (39.5%) and 25.8µm (61.4%) smaller than tibial micromotions. Tray-bone and a femoral-bone micromotions were highest in SD, and DKB activities, respectively (Fig. 2, bottom). Differences in micromotion due to bone moduli were up to 62.5%. For the tray-bone micromotion, perturbations of the tray-bone and femoral-bone alignment along the ML direction (per 1mm) resulted in 15.9% and 21.7% changes in the interface micromotions. Average changes caused by perturbations of tray-bone/femoral-bone AP alignment (1.0%/3.8%) and friction coefficient (1.0%) were much smaller (Table 1). For the femoral-bone interface, the changes in micromotions due to perturbations of implant alignments and friction coefficient were less than 6%.

DISCUSSION: This study investigated micromotions at the cementless UKA implant-bone interfaces under physiological conditions and evaluated the impact of alignment, contact friction, and bone elasticity on micromotions. The initial femoral positioning in ML has a considerable impact on the tray-bone micromotion. The mechanism was hypothesized to be the change in the moment arm altering the tray loading. In contrast, the femoral-bone micromotion was much smaller and was relatively insensitive to the factors studied, which was believed due to the angular faces of the femoral component providing significant constraint. Over 90% of the surface area <50µm was consistently found at femoral-bone interface, which reduces concern for femoral loosening.

SIGNIFICANCE: The tray-bone micromotion in UKA can be minimized by optimizing the implant's ML positioning. Perturbation of femoral-bone alignment may be preferred as it would not create under/overhang of the tibia.

REFERENCES:
[1] Pillar, et al., 1986. [2] Yang, et al., 2022. [3] Yang, et al., 2020.
[4] Zumbrunn, et al., 2020. [5] Fitzpatrick, et al., 2016. [6] Rho, et al., 1995.

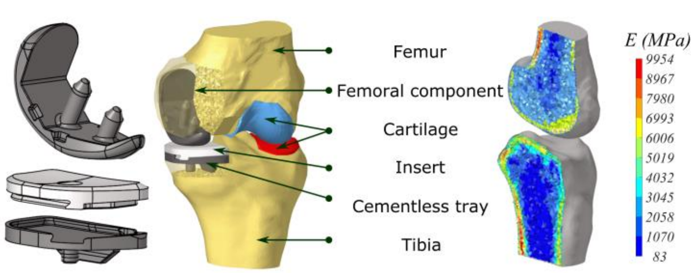


**Fig. 1.** UKA implant geometries and the computational model setup (left knee).

**Table 1.** Impact of the studied factors on the peak implant-bone interface micromotions and the average micromotions across the contact interfaces.

**Impact of studied factors on peak micromotion**

| Impact | Alignment variation (per 1mm) | | | | Friction (per 0.1) | Bone material |
|---|---|---|---|---|---|---|
| | ML (Tray) | AP (Tray) | ML (Femoral) | AP(Femoral) | Friction | Lower - Upper[3] |
| Tray-bone interface | **15.89%** | 1.03% | **21.73%** | 3.77% | 1.04% | **62.46%** |
| Femur-bone interface | 5.70% | 3.07% | 4.51% | 4.77% | 1.43% | **27.85%** |

**Impact on average micromotion across the contact interface**

| | | | | | | |
|---|---|---|---|---|---|---|
| Tray-bone interface | **21.42%** | 1.61% | **26.24%** | 3.56% | 1.76% | **58.70%** |
| Femur-bone interface | 3.24% | 6.36% | 5.26% | 5.74% | 1.66% | **39.15%** |

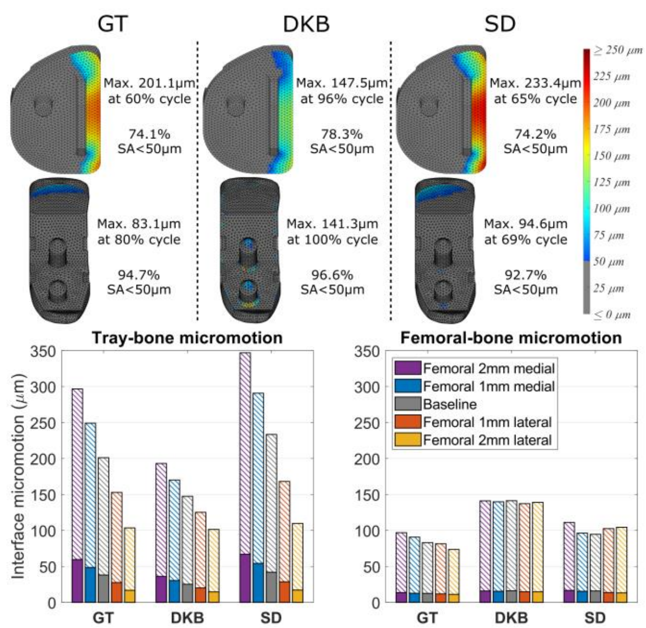


**Fig. 2.** (top) Peak interface micromotion contour maps. (bottom) Impact of femoral-bone ML alignment on the micromotions. *(Hatched bar – peak micromotion; Solid bar – average micromotion across interface)*