Extreme varus alignment of the tibial baseplate in total knee arthroplasty increases the mechanical burden on the implant fixation

Fernando J Quevedo González[1], Kathleen N Meyers[1], Joseph D Lipman[1], Timothy M Wright[1], Peter K Sculco[1]
[1]Hospital for Special Surgery, New York, NY
quevedogonzalezf@hss.edu

Disclosures: Quevedo González (LimaCorp: 1; Zimmer Biomet: 6), Meyers (N), Lipman (Exactech: 1; LimaCorp: 1; Mathys: 1; Ortho Development: 1; Wishbone: 1; Extremity Medical: 3C; EvolveOrtho: 4), Wright (Exactech: 1; LimaCorp: 1, 6; Mathys: 1; Zimmer Biomet: 6; AJRR: 9; OREF: 9; Knee Society: 9), Sculco (Depuy: 2, 3B; Intellijoint: 3B, 4, 6; EOS: 2, 3B; Parvizi Surgical Innovation: 4, LimaCorp.: 3B; Zimmer Biomet: 3B)

INTRODUCTION: Modern kinematic alignment in total knee arthroplasty (TKA) aims at restoring the native pre-disease joint articular surfaces [1], resulting in deviations from the traditional mechanical alignment, where the implants are aligned to the mechanical axes of the bones. Such deviations, especially extreme deviations, could have critical implications for the longevity of tibial components [2], particularly of cementless implants that require stable interfaces to allow bone ingrowth. Therefore, our goal was to quantify the effect of extreme varus alignment of a tibial baseplate on the bone-implant interaction in the immediate postoperative scenario. We hypothesized that extreme deviations of the tibial baseplate from the mechanical axis of the tibia will result in increased bone-implant micromotion and bone strains.

METHODS: We obtained three pairs of matched cadaveric tibiae (2 male, ages 53-77 years, bmi 19-33 kg/m^2) without any prior trauma or surgery to their knees. The bones were CT-scanned before any manipulation, and the scans included K2HPO4 bone density reference phantoms (Mindways Software, Austin, TX), allowing us to compute the bone mineral density from the Hounsfield Units. We implanted one specimen of each pair in mechanical alignment (i.e., tibial baseplate perpendicular to the mechanical axis of the bone) and 3º posterior slope using a modern cementless tibial baseplate (Physica Knee, Lima Corporate, Udine, Italy). The second specimen of each pair was implanted in 6º varus alignment, with 3º posterior slope. Accuracy of the implantation was ensured by using specimen-specific 3D printed guides to make the cuts and align the specimens when potting. The specimens were CT scanned again after implantation. The specimens were potted in epoxy (Bondo, 3M, Saint Paul, MN) 100 mm below the implant and were experimentally tested under a uniaxial compressive load of 2.8 times the body weight of each specimen to represent the worst-case during level gait [3,4]. To represent the flexion and varus/valgus moments, which are critical to capturing the worst-case scenario for the bone-implant interaction [5], we offset the force medially and posteriorly. We further offset the force medially for the specimens implanted in varus, to account for the increased moments that occur for this alignment [4]. We measured the strains in the posterior surface of the tibia and the bone-implant micromotion in the anterior-lateral aspect of the bone-implant interface using a Digital Image Correlation System (Aramis, GOM, Braunschweig, Germany). We built Finite Element (FE) models of each specimen to quantify the interaction and load transfer between implant and baseplate. We obtained the bone geometry and material properties from the preoperative CT-scans. We virtually reproduced the experimental implantation by aligning the postoperative and preoperative CT-scans. The bone was modeled as a non-homogeneous, linear elastic, isotropic material, by using empirical relationships [6,7] to relate the elastic modulus (E) to the bone density, which was computed from the Hounsfield Units with the K2HPO4 phantom. The porous zones on the backside of the tibial baseplate and the pegs were modeled as linear elastic, isotropic, and homogeneous Trabecular Titanium (TT) (Lima Corporate Udine, Italy), with E=1.1 GPa and v=0.3. The remainder of the tibial baseplate was modeled as linear elastic, isotropic, and homogeneous titanium, with E=114 GPa and v=0.33. We modeled line-to-line contact between implant and baseplate, assuming friction coefficients of 1.1 and 0.6 for the TT and rough implant surfaces, respectively.

RESULTS: For all three pairs, the experimentally measured micromotion was larger for the varus alignment than the mechanical alignment: 1410 µm vs 943 µm, 288 µm vs 30 µm, and 472 µm vs 280 µm (Fig. 1). The specimen pair with the highest micromotion suffered bone collapse during testing. From this pair, the specimen in varus suffered catastrophic collapse just after one cycle of testing. Excluding the specimens that collapsed, for which micromotion reads were compounded with the collapse, our FE models showed good general agreement with the experimental results. The RMS difference between the peak micromotion computed with FE models and the experimental micromotion was 95 µm, smaller than the threshold for a stable interface of 150 µm [8]. The strains in the posterior-medial aspect of the tibiae were increased for the specimens with varus alignment relative to their mechanical counterparts. In particular, the FE of the specimens that subsided showed high strains in the area of the collapse (Fig. 2).

DISCUSSION: Extreme varus alignment markedly increased the bone-implant micromotion and the bone strains on the posterior-medial surface of the tibia compared to when the implants were aligned perpendicular to the mechanical axis. Such increases were due to a combination of higher varus moments and changes in the underlying bone density due to the different cut. Future studies will aim at identifying the main contributors to the increased burden in varus aligned knees.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): Extreme varus deviations of the tibial component from the mechanical axis of the tibia increase the burden in the bone-implant interaction and may jeopardize implant longevity.

REFERENCES: [1] Howell, et al., Orthop Knowl Online. 2012; [2] Ritter, et al., J Bone Joint Surg. 2013; [3] Kutzner, et al., J Biomech, 2010; [4] Glenday, et al., J Orthop Res. 2021; [5] Quevedo Gonzalez, et al., J Orthop Res. 2018; [6] Anderson, et al., J Bone Join Surg. 1992; [7] Rho, et al., Med Eng Phys. 1995; [8] Jasty, et al., J Bone Joint Surg. 1997

ACKNOWLEDGEMENTS: This study was funded by Lima Corporate.

IMAGES AND TABLES:

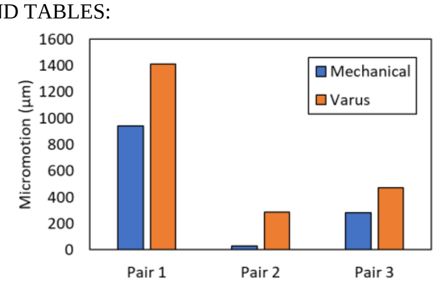

Fig. 1 – Experimentally measured bone-implant micromotion.

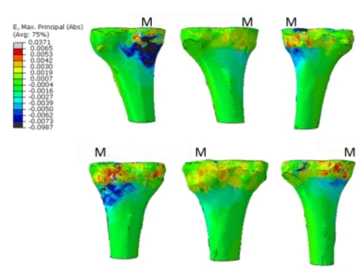

Fig. 2 – Strain distribution on the posterior aspect of the tibiae implanted at 6° varus (top row) and mechanical alignment (bottom row). M indicates medial aspect of the tibiae.