How Does a Calcar Collar Affect Strains in the Proximal Femur After Total Hip Arthroplasty Under Torsional Loading?

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Disclosures: Helbock (N), Lipman (Exactech: 1; LimaCorp: 1; Mathys: 1; Ortho Development: 1; Wishbone: 1; Extremity Medical: 3C; EvolveOrtho: 4), Puri (N), Sculco (Depuy: 2, 3B; Intellijoint: 3B, 4, 6; EOS: 2, 3B; Parvizi Surgical Innovation: 4, LimaCorp.: 3B; Zimmer Biomet: 3B), Wright (Exactech: 1; LimaCorp: 1, 6; Mathys: 1; Zimmer Biomet: 6; AJRR: 9; OREF: 9; Knee Society: 9), Vigdorchik (AAHKS: 9; Aware: 4; Corin USA: 1, 4; Depuy: 1, 3B; Intellijoint Surgical: 3B, 4; JBJS: 8; Motion Insights: 4; Ortho AI: 4; Polaris: 4; Stryker: 3B), Gausden (AAHKS: 9; BICMD: 3B; Intl. Orthopaedic Education Network: 9; Zimmer Biomet: 3B), Quevedo Gonzalez (LimaCorp: 1; Zimmer Biomet: 6)

INTRODUCTION: Periprosthetic femoral fracture (PFF) is the second most common cause of early revision total hip arthroplasty (THA) [1], and one-year mortality rates following PFF can reach 22% [2]. Clinical data and biomechanical studies suggest that collared femoral stems can reduce the risk of PFF by increasing the torque required to fracture the bone [3,4]. However, little is known about how collared stems impact the local biomechanics of the bone-implant interaction, particularly the periprosthetic bone strain distribution that is a marker for bone failure [5]. Thus, our goal was to compare the strain distribution in the periprosthetic bone between THA implants with and without a collar on a cohort of patients at risk of PFF. We hypothesized that collared stems would lower strains in the periprosthetic bone. To this end, we developed patient-specific finite element (FE) models of THA patients that suffered PFF and compared the bone strains during torsional loading to the failure strength of femoral bone tissue to determine the impact of a collar on fracture risk.

METHODS: Under IRB approval, we identified six patients from our institution that suffered early PFF after robotically assisted primary THA (5 female, age 51-75, BMI 31-40). Our standard-of-care procedure for robotic-based THA is to acquire a preoperative CT scan, which enabled us to develop FE models with patient-specific femur geometry and distribution of bone material properties. Implant geometry was reverse engineered by 3D scanning each patient's femoral stem from our retrieved implant collection. Using Joint Track Auto (https://github.com/BRIO-lab/Joint-Track-Machine-Learning), the 3D geometry of the implant and femur were aligned to anteroposterior X-rays obtained in the post-anesthesia care unit to reproduce the patient-specific implantation. FE models were developed for each patient in the "as-implanted" condition (i.e., non-collared) and with the addition of a generic collar, assuming perfect contact against the calcar bone. Models were meshed with 1-3mm linear tetrahedral elements. The bone was assigned elastic, non-homogenous material properties by converting Hounsfield units (HU) from the preoperative CT scans into elastic modulus (E) via empirical relationships [6]. The implants were assumed to be titanium alloy (E=110 GPa, v=0.33). Line-to-line frictional contact was employed between implant and bone with friction coefficients of 0.6 and 0.2 for rough and polished regions of the stem, respectively. To load the FE models, the femoral implant was internally rotated 4.5º about the stem axis, while applying 10N of axial compression (Fig. 1). Such rotation generated a resultant torque within the range of values reported in literature for torque to fracture experiments (30-85 Nm) [3,4]. Bone strains were analyzed in the proximal 100 mm of the femur, defining high risk of failure when the strains exceeded 50% of the static failure strain of femoral bone tissue [8]. We compared the non-collared and collared conditions using paired t-tests with a significance of 0.05.

RESULTS: In the non-collared condition, tensile bone strains >50% of bone strength spiraled from the posteromedial quadrant of the femur at the neck cut to the posterolateral quadrant below the lesser trochanter (Fig. 2), matching the fracture pattern seen in torsional loading experiments [7]. Adding a collar reduced the tensile strains but generated compressive strains >50% of bone strength directly below the collar near the neck cut (Fig. 2). Consequently, the addition of a collar did not change ($p = 0.21$) the bone with high risk of failure at the periosteal bone surface (Fig. 3). However, adding a collar reduced the bone volume with high risk of failure for the entire proximal bone ($p=0.005$, Fig. 3) and at the interface between bone and implant ($p=0.005$, Fig 3).

DISCUSSION: We observed that adding a collar was effective in reducing the bone with high risk of failure for the overall proximal femur and the bone-implant interface. In this way, our patient-specific FE analyses agree with prior clinical and biomechanical studies that reported the beneficial effects of a collar in reducing the risk of fracture. However, we observed that, in some patients, such reduction came at the cost of increasing the bone with compressive strains >50% of bone strength in the periosteal surface. While we attempted to understand how a collar impacts the local biomechanics of PFF, the initiation location of the fracture was unknown, and the observed increase in periosteal strains could be critical for some patients.

SIGNIFICANCE/CLINICAL RELEVANCE: Under torsional loading, while a collar reduced the bone with high risk of failure at the proximal femur and at the bone-implant interface, its effect is not universal, as the collar introduced high compressive strains in the periosteal surface that could also lead to PFF.

REFERENCES: [1] AJRR 2022 Annual Report; [2] Moreta, et al., Injury. 2021; [3] Lamb, et al., Bone Joint J. 2019; [4] Johnson, et al., J Bone Joint Surg. 2020; [5] Morgan, et al., J Biomech. 2004; [6] Morgan, et al., J Biomech. 2003; [7] Jones, et al., J Orthop Traumatol. 2015; [8] Morgan and Keaveny, J Biomech. 2001.

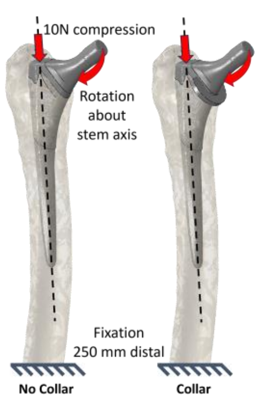

Figure 1. Non-collared and collared FE models with identical boundary conditions.

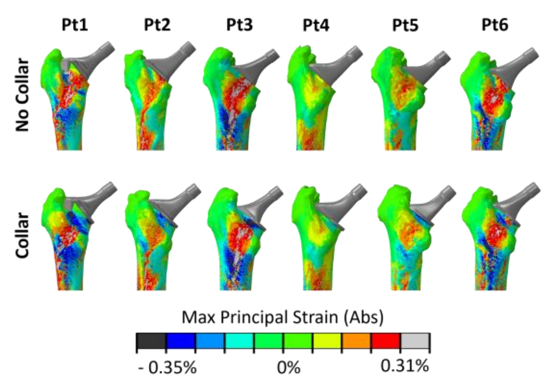

Figure 2. FE models showing posterior view of six proximal femurs of post-THA fracture patients with and w/o a collar. The strain distribution matches torsional fracture patterns seen in literature, and the collar introduces high compressive strains on the periosteal surface near the neck cut.

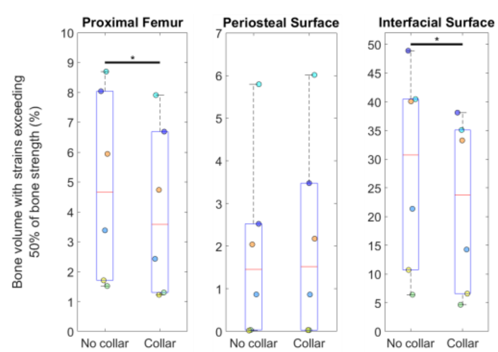

Figure 3. Failure risk of the proximal femur, periosteal surface, and interfacial surface. Colored points indicate each individual patient. A collar reduced failure risk for the proximal femur and the interfacial surface (= p<0.05).*

ORS 2024 Annual Meeting Paper No. 17