PRIMARY STABILITY OF CEMENTLESS TIBIAL TRAYS DURING STAIR DESCENT AND DEEP KNEE BEND: A MICRO-CT AND DVC ANALYSIS

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Introduction

Primary stability, the mechanical fixation between implant and underlying bone prior to osseointegration, is crucial for the long-term success of cementless tibial trays [1]. However, experimental studies on the initial internal strains between bone and implant are limited, due to previous experimental restrictions [2]. The aim of this study was to quantify, through micro-CT and digital volume correlation (DVC) analysis, the internal strain field across five cadaveric tibiae when subjected to two time-elapsed mechanical load sequences representing stair descent (SD) and deep knee bend (DKB), everyday activities known to expose the tray to posterior loading.

Methods

Five right human cadaveric tibiae were resected and impacted with a clinically employed titanium tibial tray (Attune, DePuy Synthes) by an experienced surgeon (ethics: HREC 186.20). The tibiae were potted distally, oriented with the resected surface flat. The time-elapsed loading spanned two days, the first for SD and the second for DKB. To replicate these activities, uniaxial loads were applied to the implanted tibiae through posteriorly offset prongs, the position of which matched the average position of the femoral medial and lateral condyles on the tibial tray during each load scenario [3]. The applied loads were scaled to the body weight (BW) of each donor for sequential load steps of 0.0 (preload), 0.5, 1.0, 1.5 and 2.5BW. For DKB, the peak load was extended to 3.5BW. After 20min relaxation, a micro-CT scan was acquired at each load step at 46μm/pixel (66min scan time), resulting in 45 loaded datasets. A repeated scan of the tibia in the unloaded condition (0.0BW) was taken for zero-strain error analysis (accuracy of the DVC analysis was 434με, precision 177με) [2,4]. Loaded scans were rigidly co-registered to the unloaded scan in each activity and DVC was performed (DaVis v8.3.1, algorithmic masking applied to remove air, 5-step progression with a final subvolume sidelength of 1.56mm (34pixels)) [2]. The minimum principal strain component (P_{min}) was calculated across the entire proximal tibia, before isolating subvolumes directly under the tibial tray (Fig1a).

Results

With progressive loading, increased compression of trabecular bone directly under the tibial tray was observed across all five tibiae for the two activities. There was large strain variation across tibiae and load steps (Fig 1b), with the 90th percentile ranging from -1,693με to -94,942με. For both activities, the posterior region consistently had the greatest compression across all tibiae, with peak compression concentrated in the posterior-medial region for four of the five tibiae, particularly during DKB (Fig 1a). Conversely, bone in the anterior region had the lowest compression across all tibiae. For DKB, the lowest compression occurred under the anterior-medial region of the tray (Fig 1a), whilst for SD across the whole anterior portion.

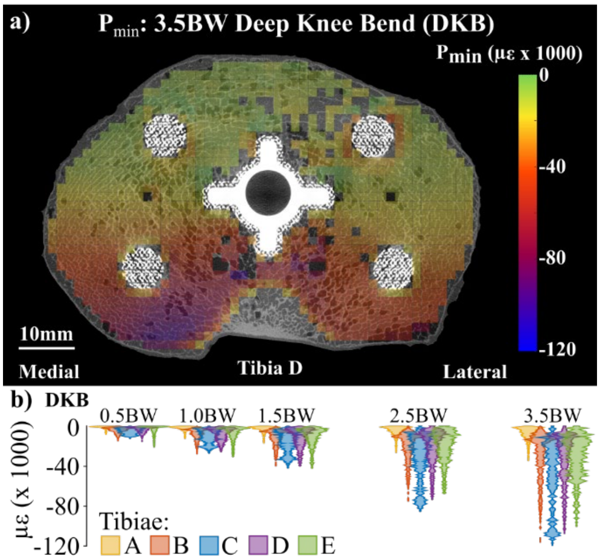

*Fig.1**a)** DKB P_{min} distribution at 3.5BW via DVC; **b)** P_{min} frequency distribution for the five tibiae during DKB.*

Discussion and Conclusion

Progressive load corresponded to increased compressive strains, quantified via DVC, with variation of the strain distribution observed across the five tibiae and the two activities. Peak compression occurred in the cancellous bone under the posterior region of the tray for both activities, with reduced compression anteriorly, consistent with migration patterns of cementless tibial trays reported in clinical studies [1]. This study provides a means to experimentally quantify the internal strain distribution of human tibiae with cementless tibial trays, thereby increasing the fundamental understanding of the mechanical interaction between bone and implant and enabling to validate finite-element models.

References

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