Progression of Micro-motion, Micro-gaps, and Trabecular Strain Shielding in Cemented Knee Replacements

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Introduction: Fixation of most tibial components in knee replacements is achieved with the use of PMMA cement. The cement interlocks with the trabecular bone bed at the time of surgery, but this trabecular interlock is lost with in vivo service [1]. This results in weaker fixation at the cement-bone interface [2] and likely contributes to aseptic loosening. To date, the local micro-mechanical environment of the interlocked cement-trabecular region has not been explored at high resolution and may provide clues as to how the resorption process occurs. There are several candidate mechanisms that could be responsible for the observed trabecular resorption including bone lysis due to fluid pumping at the interface [3] and strain shielding of the interlocked trabeculae. The goal of the present study was to quantify the cement-trabeculae micro-morphology and micro-mechanics for lab-prepared specimens (to represent in initial post op state) and postmortem retrievals (that had in vivo remodeling). We asked two research questions: RQ1: is there micro-motion between trabecular bone and cement in the immediate post-op condition and does this depend on position in the interlocked region? RQ2: after trabecular resorption due to in vivo service, does the spatial distribution of micro-motion and gap thickness change?

Methods: Fresh cadaver knees (n=8; 2 male: 64 and 70 years, 6 female: 67-85 years) were used to prepare and cement the tibial component of knee replacements. Postmortem retrieved knee replacements (n=7. 1 male: 61 years, 6 female: 69-87 years) were obtained from the university’s Anatomical Gift Program. A total of 17 cement-bone test specimens (8 lab prepared and 9 postmortem) were created from tibial tray cement-bone interfaces with 8x8mm cross-section and 16mm in length. The amount of initial interdigitation between trabeculae and cement was similar for the lab prepared (3.76±0.82mm) and postmortem (3.38±0.61mm) specimens. The specimens were mounted in a custom screw driven loading device and axial compression of 1 MPa was applied. Images of the entire interlocked cement-bone interface were obtained with and without loading using reflected white light imaging at 0.5 um/pixel. Digital image correlation was used to determine the micro-motion at 50 randomly selected point-pairs along the trabeculae-cement interface (Fig 1). The trabeculae-cement gap width was measured at the same locations. Trabecular bone strain was measured using an optical gage approach with 0.3mm gage length along the interlocked trabeculae. Data was collected as a function of distance from the cement border (Fig 1) between cement and bone.
Results: RQ1: For the laboratory prepared interfaces, there were detectable, but small amounts of cement-trabecular micro-motion (median motion: 0.56±0.40 um). Micro-motion was greatest near the cement border (0.9 um, Fig 2, dashed line), and decreased with distance from the cement border. The cement-trabeculae gap thickness (10 um) was also greatest near the cement border and diminished to 3 um deep in the cement layer. RQ2: For the postmortem retrievals, there was greater overall micro-motion (median: 4.8±4.5 um) compared to the lab-prepared interfaces (p=0.023). However, there was a great deal of variation in the micro-motion response depending on donor (Fig 2). The least micro-motion was found for a 61 year old male donor with 5 years of in vivo service; these constructs maintained interlock with minimal resorption and had very small micro-motions. In contrast, all of the other donor constructs had more micro-motion than the lab prepared constructs, and the largest difference was at the cement border. There was no correlation between age or time in service and micro-motion in the retrievals. Gaps between the trabeculae and cement were larger for the postmortem retrievals near the cement border. Measures of strain in trabeculae of the lab prepared specimens (Fig 3) indicate that strain diminishes with distance from the cement border and there was a strain concentration (increased strain) near the cement border.
Figure 2
**Discussion:** The results from this study show that the interlocked constructs of cemented knee replacements initially have small micro-motions between the cement and trabeculae, over the entire length of the interlocked trabeculae, and the micro-motion is highest at the cement border. With in vivo service, micro-motion increases at the cement border, as do local gaps between the trabeculae and cement. These findings indicate that trabecular resorption occurs first near the cement border, creating wider gaps between the trabecular surface and cement, which in turn results in more micro-motion when loaded. Away from the cement border, there is less micro-motion, and lower bone strains. It is possible that fluid pumping in gaps between the trabeculae and cement at the cement border is of sufficient magnitude to cause fluid-induced osteolysis [3]. The postmortem retrievals exhibited a wide range of interlock morphology and micromechanics, and this variation may depend on donor sex, age, and time in service. The least micro-motion occurred in a relatively young 61 year old male with 5 years of in vivo service, suggesting that robust interlock at the interface can be maintained, at least in the short term. In contrast, the two donors with the most micro-motion were female, 69 and 75 years old, with 11 and 16 years of in vivo service. Because micro-motion is clearly related to the amount of interlock remaining between cement and bone, interventions that aim to maintain trabecular interlock could improve the long-term outcome for patients with total joint replacement.
**Significance:** Total knee replacement is the most common total arthroplasty procedure performed in the US. Aseptic loosening continues to be the leading cause for revision arthroplasty. This work aims to understand where and how changes to fixation occur with in vivo service in functioning joint replacements.

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