The Micromechanical Effects of Bone Cement Polymerization on Sheep Femur Cortical Bone

Kang, Jennifer H., Gilbert Jeremy L.
Syracuse University

Introduction: Bone cement polymerization is an exothermic reaction that has been shown to decrease bone remodeling behavior significantly following implantation. However, the primary means to evaluate bone response have mostly been through histological analyses. The goal of this study was to investigate the healing response of sheep femur cortical bone following cement exposure using an alternative method, micromechanical indentation testing. Micromechanical indentation testing is performed in a spatial range that is larger than nanoindentation yet smaller than macroscopic testing. This intermediate testing range allows haversian systems, which are typically about 200-250 μm in diameter [1], to be tested with microindentation on the order of the microstructure itself. Micromechanical indents could be correlated to the microstructure at that location with Scanning Electron Microscopy, demonstrating one-to-one correlation of micromechanical properties and the microstructure at each indent.

Methods: Bone samples were obtained from a previously conducted animal study, in which sheep femurs were implanted with bone cement and allowed to heal, and were subjected to various cement exposure times of 2, 4, or 12 weeks [2]. Three sections per healing time underwent indentation tests using a custom built apparatus. Hardness, modulus, hysteresis energy, and energy dissipation factor were calculated at each indent. Micromechanical testing was coupled with Scanning Electron Microscopy (SEM, JSM-5600, JEOL, Inc. Peabody, MA) to provide information about the healing response of bone over time as well as the effects that location, within a section and with respect to the length of the femur, had on each micromechanical property. Statistical analyses were performed using ANOVA and either the Student Newman Keuls or Dunn's post hoc test. Differences were considered significant for $p<0.05$.

Results / Discussion: The hardness, modulus, hysteresis energy, and energy dissipation factor were plotted for each indent from endosteal to periosteal surfaces for each healing time sample (Figure 1). Evident variability in data led to data validation, in which specific outliers on raw data plots could be correlated to SEM images of each indent. Those outliers in which indentation testing was performed on clear structural defects were omitted from data plots. 2-week data showed greater variability between each of the three samples tested than the 4- or 12-week data. 4-week data show the least inter-sample variability and showed a clear trend of increasing hardness, modulus, and EDF from the endosteal to periosteal surface. While the 2-week data showed the highest variability between samples, it also yielded the greatest intra-sample variability. Each 2-week indentation test showed more variation in the mechanical properties with position than in the other healing time samples.

Each micromechanical property yielded significantly different results between 2- and 4-week healing times as well as between 4- and 12-week healing times. Both 4- and 12-week sections also exhibited significant differences in micromechanical properties between regions of the tested cross section (endosteum, mid region, and periosteum). Spatial variations between locations in the diaphysis were also present within a single healing time sample.

The inter- and intra- variability that was observed for each healing time may be indicators of cement effects such as the exothermic polymerization reaction and the possible residual monomer generated. The fact that 2-week data showed both the greatest inter-variability as well as the highest intra-sample variability shows that the bone response is not uniform within each section. As this variability further decreases with both 4 and 12 weeks, with 4 weeks containing the least variability, it demonstrates how possible cement effects on bone change over time. Possible contributors to the observed changes include changes in remodeling behavior, changes in bone composition, as well as changes in structure. Such contributors could be predicted based on the ability to correlate micromechanical properties at individual indents with the microstructure via SEM images (Figure 1 and 2).

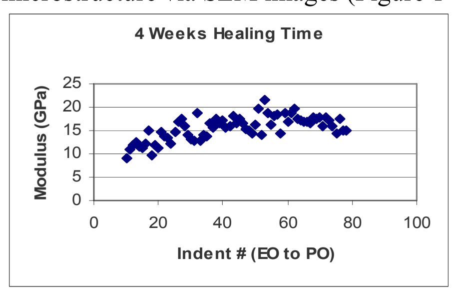

Figure 1: Modulus for 4 week cross-section from endosteum (EO) to periosteum (PO)

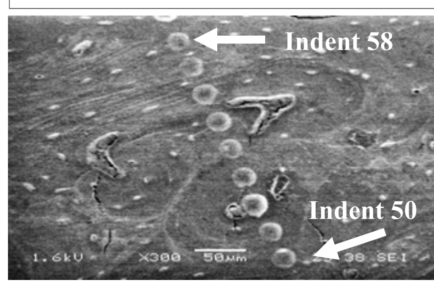

Figure 2: SEM image of Indents 50-58 of 4 week cross-section

Conclusions: These studies demonstrated the ability to directly measure and correlate micromechanical properties of cortical bone with the bone microstructure and suggest that polymerization affects adjacent bone as a function of time, region, and diaphysis location. Future work includes increasing sample size and conducting correlation analyses of micromechanical properties to bulk mechanical properties.

References:

[1] Rho JY, et al. Bone. 1999; 25(3): 295-300.
[2] Allen M, et al. JBMR Part B Applied Biomaterials, In-review.