Comparison of Bone Cements Under Dynamic Loading

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INTRODUCTION: Successful bone union is a combination of biomechanical principles and biological processes responding to local mechanical environments created by instrumentation. The balance of micromotion and stability is achieved through the screw/bone interface where loading is transferred. Clinically, screws rarely see direct axial tension but are subjected to multi-directional cyclic loading. Screw/plate constructs under body weight loading observed loosening by 5000 cycles.[1] To aid in the stabilization and hence, the likelihood of bone union in osteoporotic conditions, biocompatible bone cements are employed. More recently, bone cement has evolved with infusion of various additives. We hypothesize that a metal oxide infused bone cement, specifically, magnesium oxide (MgO) can enhance stability manifested by decreased deflection and stable performance under dynamic loading.
METHODS: Three bone cement materials (N= 6 for all) were examined: traditional PMMA cement, cement infused with Ceramic and cement infused with MgO. Cavities possessing a diameter of 9.5 mm and a depth of 35 mm were drilled in osteoporotic open foam bone blocks (10PCF) and filled with 2.5 cc of the respective cement type (Figure 1A). A 4 mm x 65 mm cancellous trauma screw was placed centrally within the cement filled cavity. Each screw was equipped with a swivel rod end to maintain axial loading during screw deflection (Figure 1B). Following a 48-hour curing time, dynamic testing was performed for 400 cycles at 1Hz from -10 N to -100 N. Load and deflection data were acquired at cycle count 5 and at 25 cycles thereafter with 2000 data points collected over a 2 second span. The net deflection over the respective loading cycles were computed, averaged for each material, plotted versus cycle count and subjected to exponential non-linear regression. Components of the analysis include the initial deflection (Yo), the rate of change (K) expressed as the number of cycles for a 50% deflection change (Half Life) and the settling deflection (Plateau). The resulting regression parameters and mean deflection for each material type over the testing regimen were analyzed with a 1-Way ANOVA and post-hoc Holm-Šídák's multiple comparisons test for differences between material types (Prism V10, GraphPad Inc.).
RESULTS SECTION: The deflection during dynamic testing is depicted in Figure 2A. Using the MgO cement as the baseline, the deflection differences during the dynamic test are seen in Figure 2B. The initial material deflections (Figure 3A) show statistically increased deflection for Ceramic infused cement compared to the other materials ($P<0.01$ for all) while PMMA and MgO infused cement were not statistically different ($P=0.3492$). The settling displacement (Figure 3B) did not result in statistically significant differences between materials ($P>5$ for all) The Half Life parameter displayed a significantly increased number of cycles for the MgO infused material, indicative of a gradual change in deflection rate over the testing regimen (Figure 3C, $P<0.0001$ for all). The average mean deflection during dynamic testing displayed a significantly reduced deflection for the MgO cement material as compared to the other materials (Figure 3D, $P<0.0001$ for all).
DISCUSSION: Screw toggle testing using simulated osteoporotic bone was conducted in a manner similar to Xie et al., where terminal deflections were reported to be 1.1 mm.[2] Despite a smaller diameter screw and use of an open foam bone block in this study, the addition of the various cement types resulted in a range of terminal or plateau deflections ranging from 1.1 mm to 1.36 mm which is good agreement with reported value. Based on the differences in deflection during dynamic testing, the PMMA cement will eventually achieve deflection equality with the MgO cement at approximately 780 cycles. The Ceramic cement will settle to a limit approximately 0.25 mm greater than the MgO cement. Bone union is a mechanical and biological process where implant/bone interfaces transfer mechanical signals. Clinically, the ambulatory period generates approximately 1000 cycles per day.[3] Thus, this study is indicative of the immediate postoperative time point. In the case of MgO cement, the greater Half Life value represents a slow or minimal change in deflection rate during this period in contrast to the other cement materials. In the current study, non-linear regression was used to identify characteristics associated with the dynamic performance of various bone cements. Infusion with MgO resulted in statistically reduced initial deflection as well as an extended duration of loading cycles where a numerically quantifiable deflection change is defined.
SIGNIFICANCE/CLINICAL RELEVANCE: Dynamic or toggle testing can be used to evaluate the effects of infused bone cement performance in osteoporotic bone under more clinically relevant scenarios versus axial pullout. In this study, bone cement infused with MgO demonstrated a significantly reduced initial, mean dynamic deflection and an increased number of cycles of gradual performance change compared to other infusion materials.
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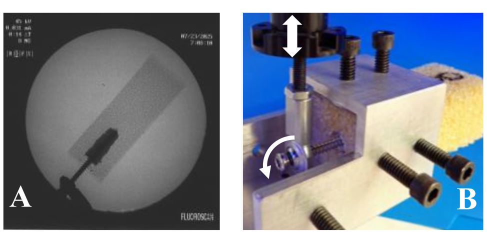
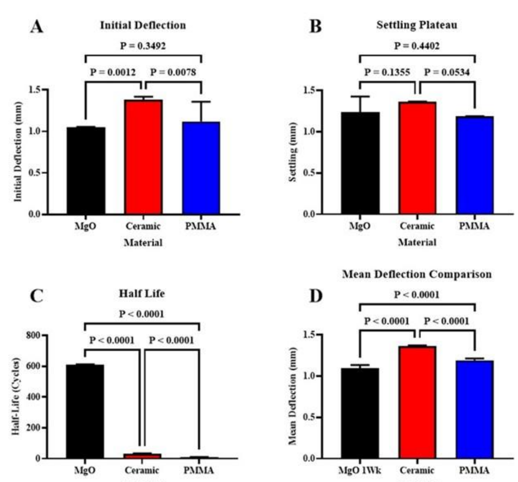


Figure 1. Dynamic testing post 48 hour curing time. A) All cement types infused within the open foam osteoporotic bone blocks. B) Cyclic testing of bone blocks with swivel rod end to maintain axial loading during screw deflection.



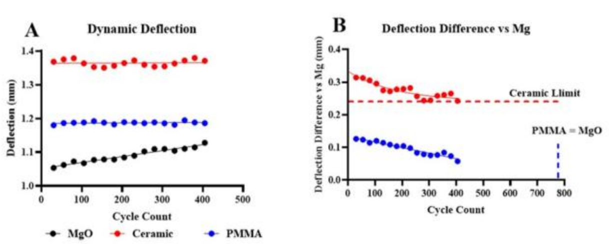


Figure 2. A) Results of dynamic deflection with non-linear fitting. B) Dynamic deflection differences per cycle using MgO cement as the baseline.

Figure 3. Dynamic testing post 48 hour curing time. A) Initial deflection, Yo. B) Settling deflection, Plateau. C) Half-life for stability. D) Mean dynamic deflection.