

Comparison of Bone Cement Dynamic Performance After Aging

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INTRODUCTION: The loosening of surgically implanted bone screws is a prominent complication in orthopaedics, particularly in the case of diminished bone density. This loss of implant stability can negatively affect patient outcomes, causing instrumentation failure, longer recovery times, and the likelihood of non-union. As bone typically fails in shear, standardized pull-out tests do not necessarily provide the correct mechanism to study screw failure under clinical scenarios. Clinically, the ambulatory period generates approximately 1000 cycles per day.¹ Furthermore, in a laboratory setting, screw/plate constructs have shown loosening by 5000 cycles under physiological loading conditions.² The addition of various biocompatible components to traditional bone cement is surmised to enhance the mechanical performance over extended time periods. We hypothesize that a metal oxide infused bone cement, more specifically, magnesium oxide (MgO), can manifest a stable mechanical environment over the early ambulatory period.

METHODS: Three bone cement materials (N= 9 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 while toggle testing (Figure 1B). Six samples of each material were assigned to a 48-hour curing time. The remaining material samples were left to be cured for 1 week. At each time point, dynamic testing was performed for 400 cycles at 1Hz from -10 N to -100 N. Load and deflection data was 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 loading cycle was 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-Sidak's multiple comparisons test for selected pair-wise differences between time points (Prism V10, GraphPad Inc.).

RESULTS SECTION: The time point deflection comparison under dynamic testing is depicted in Figure 2. The initial deflection (Figure 2A) was statistically decreased for PMMA (P=0.0007) and increased for the Ceramic infused cement (P<0.0001) at the 1-week time compared to the 48-hour time. The initial deflection of the MgO infused material was unchanged due to the curing time (P=0.9655). The settling deflection or Plateau (Figure 2B) demonstrated a similar result with Ceramic infusion manifesting an increased settling deflection (P<0.0001) and the PMMA showing decreased deflection at 1 week as compared to the 48-hour time point (P=0.0080). Again, the MgO infused cement did not display a significant difference in settling point deflection (P=0.9997). All three materials displayed a significant change in Half Life (Figure 2C) with PMMA and Ceramic infused cement showing an increase (P<0.0001 for both) Of the three materials, only the MgO cement displayed a significant decrease in Half Life (P<0.0001). At the 1 week curing time, mean deflection displayed a statistical increase for the MgO (P=0.0243) and Ceramic (P<0.0001) infused materials with PMMA showing a decrease in average deflection (P<0.0001) as compared to the 48-hour time point (Figure 3A). The average deflection changes due to curing time (Figure 3B) was only statistically different for the Ceramic material (P=0.0216 vs MgO and P=0.0003 vs PMMA). The MgO infused cement and PMMA did not display a statistically significant mean deflection change due to the curing time (P=0.1110).

DISCUSSION: Stability is key to providing an environment favorable for bone remodeling with a small degree of micromotion creating biochemical signals to encourage the process through Wolff's Law. The initial and settling deflections associated with the MgO infused cement were not statistically different over the two curing times investigated (P>0.96 for both). In contrast, the same parameters for the PMMA and Ceramic infused cement manifest significant changes (P<0.008 for both). Deflection changes displaying an increase as in the Ceramic material or a significant decrease as in PMMA are indicative of degradation and strengthening respectively. The latter can induce stress shielding. In both cases, the deviation from a stable condition is evident. Dynamic deflection changes over the number of cycles are represented by the Half Life parameter. Only the MgO infused material manifested a significant decrease in Half Life, indicating a reduced number of cycles for a specific change in deflection from the initial value, indicating a more rapid stabilization rate with the extended curing time. The other materials both displayed an increased number of cycles in Half Life relative to the 48-hour curing time. The mean deflection was unchanged over the curing time for the MgO infused material, while the other materials displayed a response similar to that of the Half Life parameter. **SIGNIFICANCE/CLINICAL RELEVANCE:** Dynamic toggle studies can illustrate effects of curing time on material performance of bone cement in osteoporotic bone as related to the initial ambulatory phase of bone healing. The near equal deflections of MgO cement combined with a more rapid setting rate demonstrated by the Half Life reduction indicated that cement infusion with MgO can provide a consistent low variability environment for bone repair.

REFERENCES: 1. Ishikawa S et al., J Rehabil Res Dev. 2011;48(10):1187-94.
 2. Grzeskowiak RM, et al., J Orthop Res. 2021 Mar;39(3):516-524

Figure 1. Dynamic testing 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.

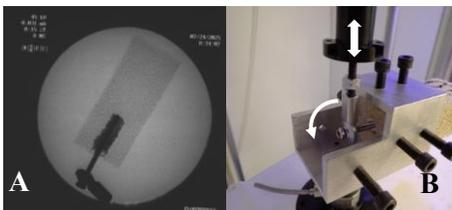


Figure 2. Dynamic testing comparison at 48 hours and 1 week curing times. A) Initial deflection, Yo. B) Settling deflection, Plateau. C) Half-life for stability.

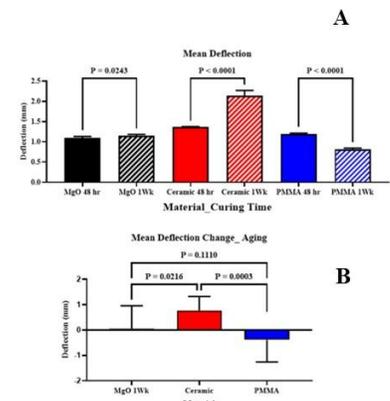
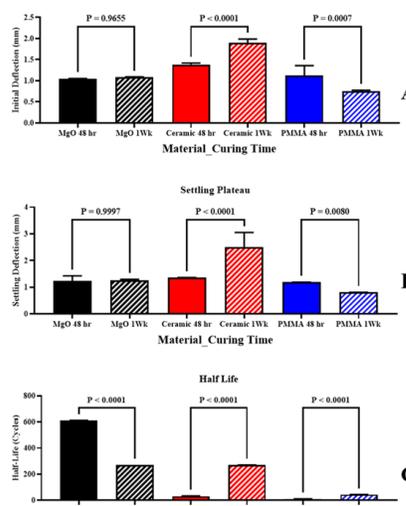


Figure 3. A) Comparison of mean deflection due to aging. B) Deflection changes due to aging.