Load Dependent Creep Behavior & Its Relationship to Crystallinity in Absorbable Materials

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Statement of Purpose: Preclinical evaluation of absorbable medical devices has traditionally focused on biocompatibility, degradation kinetics, and strength retention [1]. However, these devices are often fabricated from polymers, which can exhibit complex viscoelastic mechanics and alter their molecular structure and/or degradation rate when exposed to mechanical loading [2]. Preclinical evaluation of viscoelasticity is not typical for absorbable devices, despite the need for early structural support in vivo and observations of premature creep induced failure in vivo [3]. As the use of absorbable materials becomes increasingly prevalent in medical devices that perform a structural role (e.g., spinal implants, stents, and cellular scaffolds), it becomes critical to evaluate viscoelasticity to determine its potential role in device performance, failure, and degradation. In this study, we compared the creep and recovery behavior of two medically relevant absorbable materials and related this behavior to crystallinity in order to provide insight to possible failure modes.

Methods: Injection molded ASTM Type V tensile bars of poly(L-lactide), i.e., PLLA (Res L210S), or Poly(L-lactide-*co*-glycolide), i.e., PLGA (Res LG855S) were chosen to represent a semi-crystalline and amorphous polymer, respectively. Tensile bars were subjected to static creep in a 37°C water bath at 50N, 150N or 300N, which correspond to stresses in the linear region of the monotonic stress-strain curve either above or below the drawing stress. In addition, the forces are relevant to a range of physiologic conditions treated with absorbable devices including muscle contraction on suture in rotator cuff repair [4] and bite forces on dental fixation plates [5]. In order to determine if these materials recover creep, separate specimens were also subjected to a 2 stage creep-recovery experiment (150N load to a max creep of 1.25mm, followed by no loading, then 150N load to a max creep of 8mm, followed by no loading). Finally, % crystallinity was measured on a subset of specimens using differential scanning calorimetry (Q200 TA Instruments) to relate creep to crystallinity and its changes with load.

Results: PLGA crept continuously and withstood substantial creep in excess of 350% elongation (Fig 1) with 2 distinct zones evident on a semi-log scale. In contrast, PLLA withstood similar creep accumulation at low but not high loads (i.e., 300N) and fractured upon entering zone 2. Load had a significant effect on the rate of creep in zone 1 for both PLLA and PLGA (Fig 2, $p<0.001$, ANOVA). In addition, significant material specific differences in creep rate were also identified at low ($p<0.005$ t-test multiple comparisons for 50N & 150N) but not high loads ($p=0.7$ t-test multiple comparisons, Fig 2). While material specific differences dominated the creep behavior, the ability of PLGA and PLLA to recover from creep was similar (Fig 3), with significantly more creep recovered in zone 1 ($p< 0.005$, ANOVA). Finally, DSC analysis identified that both materials increased crystallinity following creep as compared to non-loaded controls (Table 1) but that higher creep rates were associated with the amorphous PLGA.

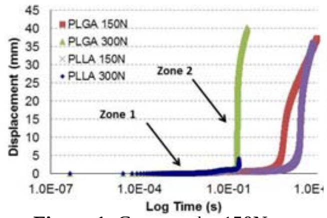

Figure 1: Creep under 150N or 300N static load (n=5-7/group)

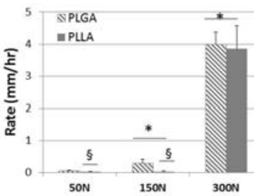

Figure 2: Creep rates in zone 1 (n=5-7 /group). * $p<0.05$ ANOVA load effect, § $p<0.005$ PLLA vs PLGA t-test, multiple comparisons

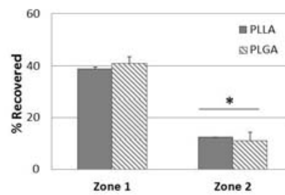

Figure 3: % displacement recovered after creepto zone 1 or zone 2 (n=6 per group). *$p<0.05$, ANOVA as compared to zone 1.

	Non-Loaded	< 350% creep	350% creep
PLLA§	20% ± 2.8%	25% ± 4.0%	35% ± 0.69%
PLGA	1.4% ± 0.8%	3.5% ± 0.4%	6.8% ± 1.1%

Table 1: % crystallinity in non-loaded control and tested specimens. § $p<0.05$, ANOVA, material; *$p<0.05$ degree of creep effect. Specimens from recovery experiments or PLLA specimens that fractured were used in the <350% creep group.

Conclusions: We identified strong tensile creep behavior for representative amorphous (PLGA) and semi-crystalline (PLLA) absorbable materials in a load dependent manner. Our study demonstrated that material specific differences dominate creep behavior and may be explained in part by material crystallinity, even though this parameter did not associate with the extent of creep recovery. Our results complement and extend static compressive creep characterization of spinal implants which has been linked to failure in an animal model [3]. Due to the growing use of absorbable materials in medical devices, characterization of their creep and recovery performance over a wide range of physiologic forces and application modes will increase assessment of short term functionality prior to degradation at the implantation site. Our creep study provides a framework for improved preclinical testing of absorbable materials that accounts for viscoelasticity and provides insight to the mechanism of load support and possible failure modes. The material and load specific creep information generated could also serve as an aid for selecting materials for use in loaded environments.

References: [1] Middleton J & Tipton AC. Biomaterials, 2000: 2335-46. [2] Schnabel W. Polymer Degradation, 1992, Oxford University Press. [3] Smit TH et al. Spine, 2008; 33: 14-18. [4] Burkhart SA. Arthroscopy, 2000, 16:82-90. [5] Uckan et al. J Craniofac Surg, 2009: 775-779.