Effect of Polymer Solution Viscosity on Injectability of Calcium Phosphate Cements

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Statement of Purpose: Calcium phosphate cements (CPCs) are used to repair voids and defects in the skeleton. CPCs are comprised of calcium and phosphate containing mineral powders which are mixed with aqueous solutions to form slurries which harden by dissolution precipitation reactions. Depending on the solution composition, powder compositions, the powder particle size distributions and the solution to powder ratio; the slurries have widely varying handling properties. Injection of calcium phosphate cements through narrow canulae or into cancellous bone often leads to phase separation of powder and liquid which limits injectability. The addition of viscous water soluble polymers to CPCs has been shown to reduce phase separation and increase injectability as measured by lower injection forces and increased volume injected for a given force. It is hypothesized that the increased injectability with polymer addition is attributable to increased solution viscosity which counteracts phase separation. The purpose of this study was to establish the relationship between injectability and solution viscosity for a model CPC.

Methods:
The cement powder was a mixture of alpha tricalcium phosphate, barium sulfate, calcium carbonate and monocalcium phosphate monohydrate. Cement solutions with different viscosities were prepared by dissolving Hydroxypropyl methyl cellulose (HPMC), carboxymethyl cellulose (CMC) and sodium hyaluronate in different concentrations into 0.075 molal sodium phosphate dibasic solution. Two different molecular weights were used for each polymer. For each injection test, cements were mixed and 5 cc of cement was loaded into a 5cc syringe. The cement filled syringe was attached to a container filled with a packed bed of 2mm glass beads to simulate cancellous bone. An Instron was used to displace the syringe plunger and inject cement at a constant rate of approximately 6cc/min while a load cell recorded injection force. Compressive strength of cured cement and setting force as a function of time were performed to study the effect of the water soluble polymers on cement properties.

Results / Discussion:
Figure 1 shows injection profiles for cements mixed with sodium hyaluronate solutions with varying viscosity (molecular weight ≈ 700,000 Da). Figure 1 shows that injection force is reduced with increased solution viscosity. This is somewhat counterintuitive since increased injection force is usually associated with increased viscosity. The injection force decreases with increased solution viscosity since phase segregation is reduced. Phase segregation results in cement with reduced solution in the delivery device which leads to a higher viscosity paste and increased injection forces. The solutions with increasing viscosity show much smoother injection curves as phase separation is reduced. Figure 2 shows Injection profiles for HPMC containing solutions which is similar behavior to Figure 1 for sodium hyaluronate. Figure 2 shows that at lower viscosities (11 cp for example) the injection profiles can show poor reproducibility because of phase separation. All polymers tested showed smooth injection profiles with complete injection when the solution viscosity was above 90 cP. There were some differences in injection behavior for different polymers for a given viscosity range, but overall the differences were small. Polymer molecular weight for a given viscosity had little if any influence on injectability. Except for HPMC containing cements which showed compressive strengths as low as 32 MPA, the compressive strength for cements with different polymers was approximately 40 Mpa which was similar to the cement without polymer. Setting force was between 130 lbs and 190 lbs for 9 minutes setting at 37º C, compared to 200 lbs for cement without polymer; therefore setting was not strongly influenced by the polymers.

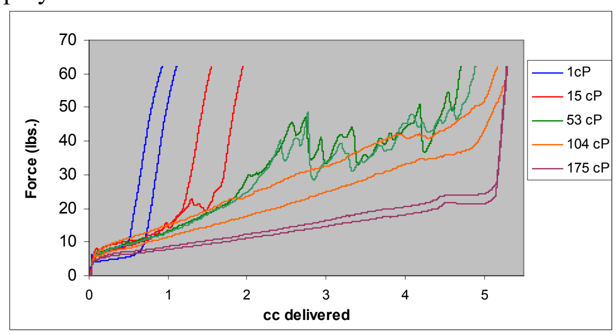

Figure 1. Injection force with cement injection into 2mm glass bead model for cements with sodium hyaluoronate polymer.

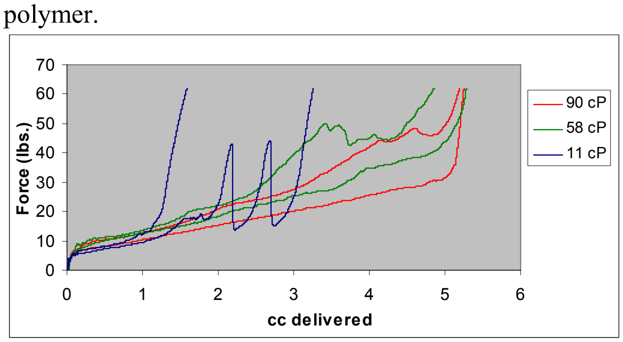

Figure 2. Injection force with cement injection into 2mm glass bead model for cements with HPMC polymer.

Conclusions:
Increased solution viscosity leads to reduced injection force and increased injection volume for the model CPC tested. Solution viscosities of above 90 cP led to smooth reproducible injection for all polymers tested. Except for HPMC, the polymers had little effect on cement compressive strength or setting kinetics as measured by the setting force test.