Optimization of novel two-solution based bone cements for vertebroplasty and kyphoplasty applications

Danieli B.C.Rodrigues, Julie M. Hasenwinkel
Department of Chemical and Biomedical Engineering, Syracuse University, Syracuse NY, 13244

Statement of Purpose: Percutaneous vertebroplasty (VP) and kyphoplasty (KP) are relatively new techniques developed to stabilize fractured vertebral bodies caused by compression fractures (VCF) secondary to osteoporosis and other lesions[1-3]. Both procedures involve percutaneous injection of different formulations of bone cements into the fractured vertebrae in order to restore functionality and reduce pain. According to Lewis[2] some of the desirable properties of injectable bone cements for VP and KP procedures comprise very high radiopacity, easy of preparation and handling, easy injectability in the vertebral body, low curing temperature and setting time of about 15 minutes. The goal of this work is to develop novel two-solution bone cements composed of varying concentrations of cross-linked poly (methyl methacrylate) PMMA microspheres and nanospheres added to linear PMMA in order to control cement viscosity, the polymerization exotherm and mechanical properties. In this work, injectability, flow rate and exothermal properties of cements prepared with different compositions will be discussed.

Methods: Two-solution bone cements were prepared as described by Hasenwinkel et al.[4] with two different polymer -to-monomer ratios (P:M = 1:1 and 1.1:1). An additional variable in the modified two-solution cements is the presence of two polymer phases: 1) dissolved linear PMMA (P_L) and 2) dispersed cross-linked PMMA microspheres and nanospheres (P_b) both synthesized with 25% v/v cross-linker (EGDMA) via suspension and soap-free emulsion polymerization techniques, respectively. Cements with different P_b:P_l ratios (from 1:1 to 4:1) for each P:M composition were prepared and delivered through a cannula (15 cm long, 12 G diameter) for characterization of injectability and flow rate. These experiments provided information on the compositions suitable for efficient delivery. In order to study the setting characteristics and maximum polymerization temperature of selected compositions, exothermal tests were performed according to standard specifications (ASTM F451-95) and also using a designed mold to accommodate a volume of cement close to the volume to be delivered into the vertebrae.

Results: One of the most important findings of this work is the fact that the cements prepared with microspheres as part of the polymer phase were subjected to a large variability in flow rate during injection. Shear induced demixing was observed to occur as a result of the stress acting asymmetrically on the restricted environment of the needle combined with the relatively large diameter of the microspheres (50-100μm), which makes diffusion of monomer somewhat difficult. To circumvent this problem cements containing nanospheres (300-350 nm) were prepared. These cements did not present any degree of demixing during delivery and showed a very homogenous appearance. Table 1 shows the injection time and standard deviation to fill a fixed volume of 3 cc for six different cement compositions prepared with nanosperes. Cements prepared with microspheres presented longer injection times at the same compositions due to the separation of the monomer phase, although the viscosity of these cements was significantly lower.

Table 1. Injection times (in seconds) of cements prepared with nanospheres.

P_b:P_l	P:M 1:1	P:M 1.1:1
1:1	89 (± 1)	304.33 (± 4.04)
1.5:1	56 (± 1)	256.66 (± 15.27)
2:1	72.3 (± 6.8)	326 (± 14.422)

In order to lower viscosity and increase the working time of commercial cements, surgeons usually alter the P:M ratio, which may ultimately lead to higher temperatures reached during polymerization. The exothermal characteristics of cements prepared with nanospheres and microspheres were compared with standard two-solution bone cements (STSBC) and the results for the composition P:M 1.1:1 are illustrated in Figure 1. Both cements showed lower maximum temperature and significantly longer setting times when compared to standard two-solution cement (P:M 0.9:1).

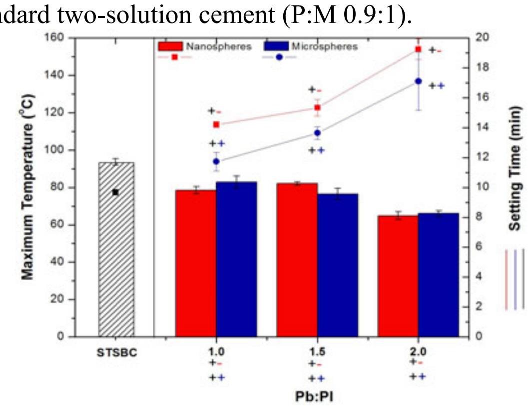

Figure 1 – Maximum temperature (bars) and setting time (line and symbol). (+-) and (++) represents a significant difference between nanospheres and STSBC and between microspheres and STSBC, respectively, at a significance level α =0.05.

Conclusions: The results showed that two-solution based cements prepared with nanospheres are suitable for quick delivery through a small cannula. The exothermal characteristics are improved compared to standard two-solution cements and the setting time is increased for increasing P_b:P_l ratios. The setting time is shown to be close to commercially available cements currently used in KP/VP procedures (varying from 15-20 minutes).

References:

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