Viscosity of injectable two-solution bone cements prepared with cross-linked PMMA poly (methyl methacrylate) microspheres and nanospheres for use in percutaneous kyphoplasty and vertebroplasty

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Statement of Purpose: The viscosity of acrylic cements used for restoring vertebral fractures is a critical factor in kyphoplasty and vertebroplasty procedures. According to Lieberman[1], the difficulty of forcing cements through small needles and the risk of cementing them during surgery call the attention for the development of novel materials with tailored viscosities and longer setting times. Currently, no standardized formulations meet the viscosity criteria for use in the spine[1-3]. The goal of this work is to determine the viscosity range of two-solution based cements that enables delivery of an appropriate volume of material into the vertebrae using a model applicator. It has been previously shown that the viscosity of two-solution cements can be manipulated by subtle changes in the polymer-to-monomer ratio and by the addition of cross-linked beads in the linear polymer phase[4]. Viscosities of cements prepared with varying compositions of cross-linked PMMA microspheres or nanospheres will be presented.

Methods: Two-solution bone cements were prepared with varying concentrations of polymer-to-monomer (P:M), as described by Hasenwinkel et al.[5] An additional variable added to these materials is the presence of cross-linked (25% v/v EGDMA) PMMA microspheres or nanospheres (P_b) added to the linear PMMA (P_L) phase (designed as P_b:P_l ratio). PMMA cross-linked microspheres (50-100 μm) and nanospheres (300-380 nm) were synthesized in house via suspension and soap free emulsion polymerization routes, respectively. Steady shear viscosity was measured using a rotational viscometer (Brookfield, DV-E) at speeds varying from 2 to 60 rpm. The viscosity of cements prepared with microspheres was initially measured for a broad range of compositions, P:M from 1:1 to 1.4:1 and P_b:P_l ratios from 1:1 to 4:1, over a course of four weeks in order to observe the degree of swelling with storage. Cements containing nanospheres were tested at six different combinations of P:M and P_b:P_l specifically selected based on the handling properties of cements prepared with microspheres. Results are compared with standard two-solution bone cement (STSBC, P:M 0.9:1) containing linear PMMA.

Results: Cements composed of microspheres showed significantly lower viscosities than cements prepared with nanospheres at the same P:M and P_b:P_l ratios. This fact may be a result of the improved diffusion of monomer into the smaller beads and improved mixing observed with these cements. The viscosity of the former cements decreased with an increase in P_b:P_l at all P:M ratios explored. This decrease in viscosity, however, is apparent for P_b:P_l > 2.5, since at these compositions the cements showed a gritty and dry handling, which makes viscosity measurements and flow more difficult and therefore, not suitable for delivery with a needle or cannula. The viscosity of cements prepared with nanospheres showed an opposite trend, increasing with increasing P_b:P_l. Similar to cements prepared with microspheres, the handling of cements with increasing concentration of nanospheres (Pb:Pl > 2) becomes gritty and more difficult to deliver. Figure 1 shows a comparison between viscosities of STSBC and cements prepared with nanospheres and microspheres at compositions observed to be suitable for delivery with a needle. The viscosities of all compositions tested are significantly lower than the STSBC even at higher P:M ratios. Cements containing nanospheres showed a highly non-Newtonian trend behaving in accordance with the power-law relationship for non-Newtonian fluids. In contrast, cements containing microspheres showed more linear and less shear sensitive behavior, probably due to the presence of more monomer in the cement matrix.

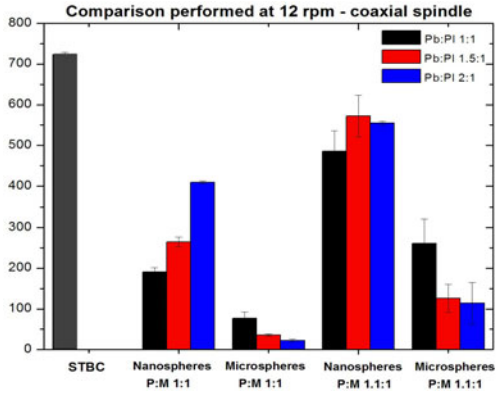

Figure 1 – Viscosities of two-solution based cements.

Conclusions: Although, the compositions of cements prepared with microspheres showed significantly reduced viscosities and therefore, possibility of using increasing P:M concentrations, separation of monomer during shearing of these cements posed restriction to their use for KP/VP applications. Cements in a more liquid form have more free monomer available to enter the circulatory system and cause adverse reactions; nevertheless cements prepared with nanospheres presented appropriate viscosities, handling, homogeneity under shearing and reduced viscosity compared to STSBC. The viscosities suitable for delivery with a model applicator are in the P:M range of 1:1 to 1.1:1 with varying P_b:P_l in the range 1:1 to 2:1. These cements will be injected into porcine and cadaver vertebrae in future studies for access of the degree of extravasation and mechanical properties.

References:

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