Introduction
Polymethylmethacrylate (PMMA) bone cement is a well-established material used in orthopedics surgery both for augmenting bone structure and as an adhesive for implant fixation. In addition, PMMA can be used independently for reinforcement of weakened or fractured bones as well as for bridging large bone gaps. Such large volumes of PMMA produce significant heat dissipation due to high temperatures generated during polymerization. It has been proven that thermal necrosis of tissue can occur at or above the range of 45°C to 60°C [1-3] depending on the duration and extent of heat exposure. As such, the high polymerization temperatures of bone cement (well over 60°C) make it (i) unsuitable as a bulk material for bone reinforcement, and (ii) unsafe for handling in molding preformed structures.

Methods
In order to reduce the maximum temperature of PMMA bone cement during polymerization, a heat sink device was designed consisting of a hollow heat-conducting aluminum rod. The heat sink was sealed at the bottom end. Air was then circulated through the heat sink producing convective heat transfer away from the cement.

Thermal experiments were performed using PMMA cement (Hygenic Dental Cement, Coltene Whaledent Inc.) prepared according to standards outlined by the producer. After hand mixing for 1 minute, the cement was poured into a custom Teflon mold (Fig. 1) designed to approximate practically achievable geometries and volumes (Fig. 2). Specifically, this mold was designed to simulate reinforcement of an osteoporotic femur (Fig. 2a). The mold was equipped with thermocouples (TC) placed to obtain geometrically asymmetric temperature measurements along the surface of the polymer material during polymerization (Fig. 1b).

Experimental temperature reduction effects of the device on bone cement. TC numbers correspond to locations indicated in Figure 1.

Discussion
A novel heat removal method has been proposed to reduce the effects of thermal necrosis by bone cement implants. Experiments showed significant reductions in temperature, and our model showed that further temperature reductions to levels below thermal necrosis were possible.

References