Multiwall Carbon Nanotubes Alter the Thermal Profile of Antibiotic Laden Bone Cement

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Polymethylmethacrylate (PMMA) is an established biomaterial that has numerous applications in medicine, especially Orthopaedic surgery. One such application involves the localized delivery of antibiotics to bone. The potency of some added antibiotics is reduced due to the exothermic nature of curing bone cement, and thus the efficacy of the antibiotic may be compromised[1]. Temperature management of antibiotic laden bone cement is important, thus, the extraordinary thermal conductivity of multiwall carbon nanotubes (MWNTs), is of particular interest[2]. This material was previously shown to enhance the mechanical properties of bone cement[3]; however, the thermal benefits of MWNTs in bone cement have not been explored. The purpose of this study was to test the null hypothesis that the addition of multiwall carbon nanotubes has no effect on the thermal characteristics of antibiotic-laded bone cement.

Methods

As produced[3] MWNTs (~25nm OD; ~100µm length) were treated in a nitric acid bath to remove the residual catalyst. Varying amounts, 0.17%, 0.67%, and 1.34% (by weight), of MWNTs were disaggregated and dispersed throughout dry pre-polymerized bone cement powder using a dual-blade shear mixer. Thirty-gram batches of hand-mixed powder were passed through this mixer 3X to ensure complete dispersion of the MWNTs; dispersion was confirmed by scanning electron microscopy. Liquid monomer was prepared according to standard commercial formulations[4]. A clinically relevant (0.06 g, 2.5% by weight) dosage of Tobramycin (X-Gen Pharmaceuticals, Big Flats, NY) was added to selected cement groups.

Components were manually mixed at room temperature. Approximately 20 mg of material was quickly transferred to an aluminum sample pan, covered, pressed, and then placed in a specimen container in the chamber of a differential scanning calorimeter (DSC). The chamber was quickly heated to 37°C and maintained for 15 minutes. The exothermic heat flow (thermogram) was recorded in triplicate for each MWNT and antibiotic loading. Maximum heat flow (HF_{max}) and the width at half maximum heat flow (D) parameters were measured from these thermograms. Mean values of HF_{max} and D were analyzed by using a 2-way ANOVA.

Results

Thermograms collected from DSC (Fig. 1) showed that the MWNTs and the antibiotic decreased the maximum heat flow (HF_{max}) and increased the full width at half maximum heat flow values (D) (Table 1). MWNTs were associated with a 25-85% reduction in HF_{max} and a 37-440% increase in D ($p<0.001$). Antibiotic addition was associated with a 40% reduction in HF_{max} and a 90% increase in D ($p<0.001$). The interaction between the heat flow reduction caused by both MWNTs and antibiotic was significant with a 41-76% reduction in HF_{max} and a 46-223% increase in D ($p<0.001$).

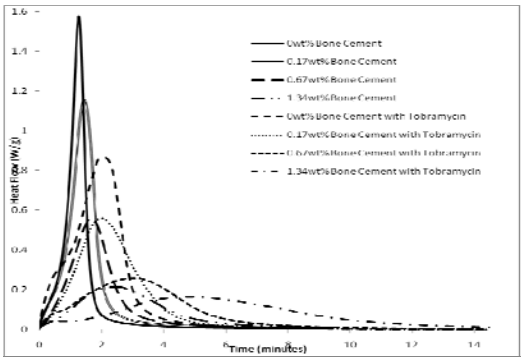

Figure 1. Average Heat Flow Curves for Pure, MWNT Loaded, and Antibiotic Loaded Bone Cement

Table 1. Means ± Standard Deviations of HF_{max} and D

MWNT (by wt)	Tobramycin (grams)	HF_{max} (W/g)	D (min)
0%	0	1.36±0.20	0.91±0.17
	0.06	0.82±0.05	1.72±0.17
0.17%	0	1.04±0.14	1.25±0.14
	0.06	0.48±0.10	2.51±0.61
0.67%	0	0.48±0.08	2.19±0.13
	0.06	0.29±0.03	3.65±0.06
1.34%	0	0.20±0.02	4.90±0.56
	0.06	0.20±0.04	5.55±1.21

Discussion

This is the first known report showing that MWNTs can substantially alter the flow of heat liberated during the polymerization of bone cement. We thus reject the null hypothesis and note that these data stir renewed interest in this established biomaterial because of the simultaneous benefits attributable to: 1) greater antibiotic potency, 2) fewer "hot spots" that can nucleate fatigue cracks, 3) greater biological viability of the bone-bone cement interface, and 4) mechanical strengthening of the matrix otherwise weakened by antibiotic incorporation. These benefits support the claim that MWNTs in antibiotic laden bone cement can result in enhanced clinical performance of cemented total joint implants. This study is presently ongoing to quantify the effects of varying antibiotic types and dosages in bone cement loaded with MWNTs.

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References

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