Radiofrequency Electric-Field Interactions with Purified Metallic and Semiconducting Single-walled Carbon Nanotubes for Applications in Non-invasive Cancer Hyperthermia

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The size-dependent optical, magnetic and electrical properties of various nanoparticle (NP) materials are currently being exploited for cancer hyperthermia therapy [1-3]. An alternative line-of-thought for expanding NP-mediated cancer heat therapy is based on the interaction of radiofrequency (RF) energy with nanomaterials such as carbon nanotubes and gold NPs. It has been hypothesized that such heat-inducing interactions could initiate targeted hyperthermia or thermal ablation within cancer cells.

Recent work has shown that both gold NPs and single walled carbon nanotubes promoted *in vitro* and *in vivo* RF thermal ablation of hepatocellular, colorectal, and pancreatic cancer [4, 5]. However, to date, only the heating rates (HRs) and theoretical mechanism of heat production for gold NP solutions have been fully quantified[6]. In order to fully optimize RF-NP-mediated cancer therapy the interactions of RF-energy with alternative nanomaterials must also be analzyed.

In these regards, highly enriched (>95 %) full-length metallic and semiconducting single-walled carbon nanotubes (m-SWNT/s-SWNT) suspended in 2% Pluronic F108 aqueous solutions were exposed to a 90 kV/m electric-field at an operating frequency of 13.56 MHz. HRs were recorded as a function of SWNT concentration across the range 1-100 mg/L via an infrared camera. HRs were found to be 30x greater than citrate-capped gold NPs of diameters 5-10 nm on a mg/L basis. Overall the s-SWNT suspensions were shown to heat to a greater extent than their m-SWNT counterparts.

To investigate the heating rates (HRs) of SWNTs in a conductive host (in accordance with recent theoretical predictions[7]) we suspended the SWNTs in aqueous NaCl solutions of varying NaCl molarity (0.001 - 1000 mM). The HRs (Fig 1.) were significantly attenuated for NaCl molarities >1 mM but gradually increased for values < 1 mM indicating a molarity-dependent heating relationship, which is important for biological applications. The effect of HRs versus SWNT aggregation was also investigated by means of different probe sonication times (1, 3, and 9 minutes). Optimized HRs were found for sonication times of 3 minutes indicating that SWNT aggregation plays an important role in the heating mechanism. Aggregation states were also analyzed using atomic force microscopy (AFM), scanning electron microscopy (SEM), and Raman spectroscopy at excitation wavelengths 514 nm and 785 nm. X-ray photoelectron spectroscopy (XPS) was used to help verify that residual iodixanol surfactants (from the enrichment procedure) had been eliminated.

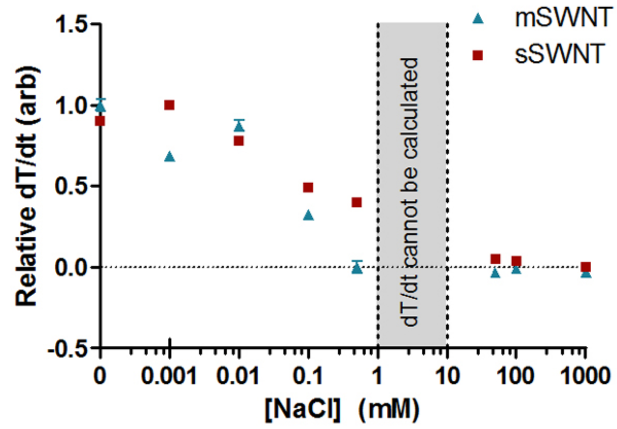

Fig 1: Normalized relative heating rates for m-SWNT/s-SWNTs suspended in aqueous NaCl solutions of varying NaCl molarity.

Finally, a theoretical framework has also been developed to elucidate the heating mechanism, which incorporates the polarization and alignment of SWNT suspension under a high-power RF field. It is thought that either s-SWNTs or m-SWNTs can be used as effective thermal agents for non-invasive RF cancer therapy.

References

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