Electrically Conductive Biopolymers Incorporating Carbon Nanotubes

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Introduction

Our goal is to create electrically conductive biopolymers for biomedical applications (e.g. biosensors, cardiac and nerve tissues). Incorporation of single-walled carbon nanotubes (SWNT) into polymers can make them conductive. We are investigating composites of collagen Type I and SWNT with embedded cells, and expect that collagen-SWNT interactions will allow us to disperse and align the nanotube phase in the matrix. Figure 1 illustrates the possible mechanisms of SWNT incorporation into collagen gels. Dispersed/solubilized collagen and SWNT can interact in an aqueous medium (left-hand panels). When collagen fibrillogenesis is initiated, SWNT may become incorporated into the triple-helical collagen molecule (upper middle panel), or may remain as a separate phase (lower middle panel). In either case SWNT become incorporated into the collagen fibril (right-hand panel) as fibrillogenesis proceeds, forming a collagen-SWNT composite material.

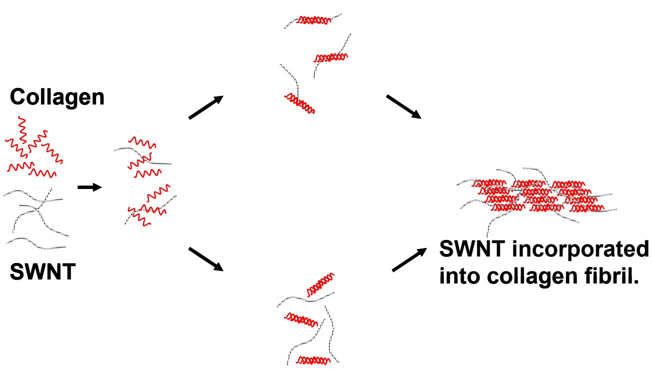

Figure 1: Schematic of process by which CNT can be incorporated into collagen fibrils

Previsously we have examined the cellular response to the SWNT in these composites. In the present study, we investigated the interaction between collagen and SWNT, and the resulting effects on electrical conductivity.

Methods

Cell seeded collagen-SWNT constructs were created by combining either rat aortic smooth muscle cells or human dermal fibroblasts with SWNT solution, concentrated culture medium, 10% fetal bovine serum and acid-solubilized bovine collagen Type I. Constructs were gelled by neutralization and elevation of the temperature. The initial cell and collagen concentrations were 1.0 million cells/mL and 2.0 mg/mL, respectively. SWNT concentrations were 0 wt% (control), 0.8 wt%, 2.0 wt%, and 4.0 wt%. Constructs were kept in culture for 3 days post embedding before subsequent testing was performed.

Gel compaction was measured at days 1 and 3. Protein secondary structure was assessed using Fourier transform infrared analysis (FT-IR) with deconvolution of the amide I band. Electrical conductivity and permittivity were measured at day 3 for constructs containing 0 wt%, 0.8 wt%, 2.0 wt%, and 4.0 wt% SWNT using a bio-impedance spectrum analyzer from 5kHz to 50kHz with a two point silver-chloride electrode.

Results and Discussion

We have shown previously that cell viability and morphology are not adversely affected by the incorporation of up to 4.0 wt% SWNT into cell-seeded collagen constructs at both day 3 and day 7 in culture. In addition volume compaction at day 7 was the same in culture of all constructs.

FT-IR showed no significant changes in the Amide I band of the collagen spectra, and Raman spectroscopy showed the expected SWNT spectral peaks. Absolute electrical conductivity and conductivity normalized to volume compaction is shown in Figure 2. Figure 3 shows corresponding permittivity values.

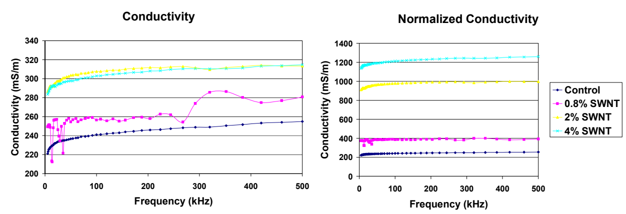

Figure 2: Conductivity of collagen-SWNT composites.

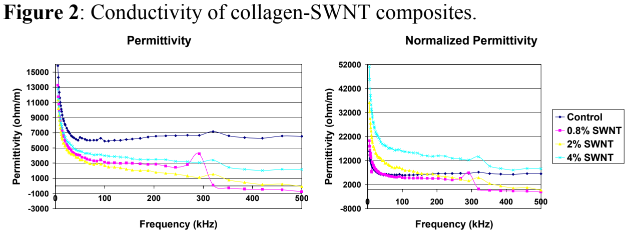

Figure 3: Permittivity of collagen-SWNT composites.

Absolute conductivity of samples increased with increasing SWNT content. When these values were normalized for gel compaction, this trend was even more evident. Assessments of permittivity revealed similar trends for collagen and SWNT samples.

Conclusions and Future Work

Incorporation of SWNT increases the electrical conductivity of biopolymer composites in direct relation to SWNT loading. Importantly, SWNT can be incorporated into collagen constructs without adversely affecting cell viability, collagen structure or gel compaction. We therefore have created electrically conductive biopolymer composites containing living cells.

Our current research is focused on gaining a better understanding the interactions between SWNT and collagen fibrils. In particular, we hope to use the process of collagen fibril alignment to entrain and align SWNT, thereby inducing directional properties and leading to increased conductivity. Our overall goal is to produce anisotropic collagen-SWNT composite biomaterials that exhibit improved electrical and mechanical properties compared to pure collagen for a variety of applications.