Soft and Conductive Hydrogel Nanofibers for Electrode-Tissue Interfaces

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Statement of Purpose: Implantable bionic devices interact with electrically active living cells such as nerve and muscle cells through translation of biological signals to electrical signals at the electrode-tissue interface. In these devices, long-term functionality of the biotic-abiotic interface is vital. While existing electrodes are fabricated from biocompatible metallic materials; the hard, dry, static nature of these metals does not conform to biological tissue. Therefore, the quality of recording and stimulating signals often deteriorates, due to the process of electrode encapsulation by fibrous tissue formation and cell death in the vicinity of the electrodes[1]. Conducting polymers (CPs) are attractive alternatives to conventional implant materials due to their high electrical conductivity and biocompatibility[2]. While CPs have mechanical properties more similar to biological tissue than metals, they are still more rigid than most native tissues, limiting their biomedical applications. Incorporation of soft hydrogels with the CPs may lead to an ideal material for soft electronics, interfacing with biological systems. The goal of this study was to fabricate electrode-free soft conductive materials for bioelectronics. CPs cannot be fabricated into nanostructures without using a hard templating method. Here, we present a novel fabrication method with fewer steps including the electrospinning of poly(ethylene oxide) (PEO)/ pentaerythritol triacrylate (PETA) solutions with 0 to 25 wt% of conducting polymer poly(3,4-ethylenedioxythiophene): polystyrene sulfonate (PEDOT:PSS) nanoparticles.

Methods:. PETA-PEG-PEDOT:PSS nanofiber were formed using electrospinning method and cross-lined using UV irradiation. Surface morphologies and diameters of nanofibers were characterized using scanning electron microscopy. Energy-dispersive X-ray spectroscopy was performed on nanofibers to confirm incorporation of PEDOT:PSS during electrospinning. Impedance spectroscopy and cyclic voltammetry were used to characterize the electrical performance of conductive hydrogel nanofibers. Tensile mechanical tests were conducted using mechanical tester with a 10N load cell to measure the elastic modules of nanofibers.

Results: The diameter of conductive hydrogel nanofibers ranged between 220 nm and 435 nm (**Fig 1b-1f**). The inclusion of higher amounts of PEDOT:PSS decreased the impedance of the substrates and increased the surface area under the cyclic voltammetry curve. The more PEDOT:PSS included in the nanofibers, the larger the reduction in impedance were observed (**Fig 1h and 1i**). The addition of the PEDOT:PSS nanoparticles into hydrogel nanofibers decreased the swelling ratio of the material from 90% for plain nanofibers (0 wt% PEDOT:PSS) to approximately 40% for those containing 25 wt% PEDOT:PSS nanoparticles. The average Young's modulus reduced from 14 ± 1.6 kPa to 4.3 ± 0.5 kPa as the percentage of PEDOT:PSS increased from 0 to 25 wt%.

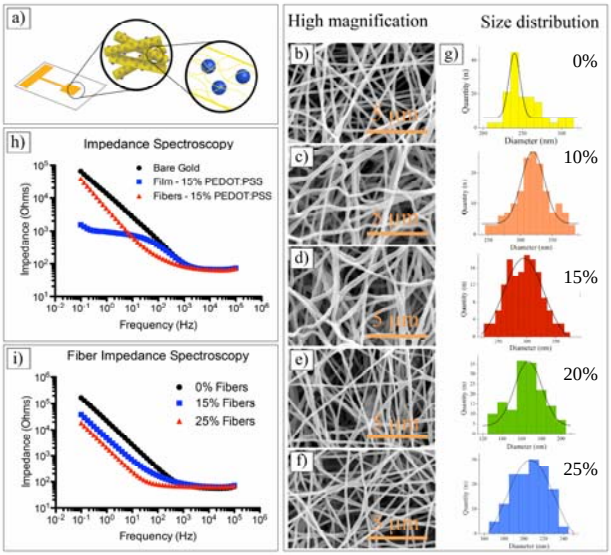

Figure 1. a) Schematic illustration of PETA:PEDOT:PSS nanofibers, b-f) SEM image of 0 to 25 wt% of PEDOT:PSS nanofibers, g) the size distribution of PEDOT:PSS nanofibers, h) impedance spectroscopies showing changes in impedance due to addition of 15% PEDOT:PSS films or fibers to the electrode and i) differences between the impedance of fibers with varying PEODT:PSS content.

Conclusions:
The incorporation of PDOT:PSS nanoparticles into a PEO-PETA resulted in: (1) An easy-to-process conductive nanofibers that can be fabricate using electrospinning method. (2) A soft nanostructured hydrogel with a young's modulus similar to soft biological tissues, greatly increasing its biomedical application. (3) A hydrogel material with a reduced swelling ratio, possibly more ideal for intracranial implantation. (4) A conductive material with significantly improved conductive properties compared to plan hydrogls. Future investigations will be (1) incorporation of drugs and biomolecules for electrically controlled drug delivery, and (2) *in vitro* biocompatibility and *in vivo* brain responses to the implanted conductive hydrogel nanofibers.

References:
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2- Ravichandran, R., J. R. Soc. Interface, 2010, 7, pp. S559-79.