Mechanical testing of metallic and polymeric intrafascicular electrodes

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Abstract - **We are exploring alternatives to Pt/Ir wire for constructing ultra-flexible neural intrafascicular electrodes suitable for chronic implantation. In this study we measured the flexural properties of several kinds of fine metal wires and conducting polymer fibers. The fibers were made either of intrinsically conductive polymers (polyaniline, polythiophene) or good mechanical polymers (nylon, Kevlar). The latter were made conductive through sputter coating with a thin layer of platinum. While the fiber flexibility (moment required for a 7.5° deflection) of the nylon and Kevlar fibers ranged from 10-35 μg-cm, some 50 to 150 times less stiff than Pt/Ir wire, their tensile strengths were approximately equal to that of Pt/Ir wire. Polymer fibers represent promising materials for ultra-flexible nerve electrodes.**

I. INTRODUCTION

Improving the long-term performance of chronically implanted intrafascicular electrodes requires finding a material that offers improved mechanical biocompatibility over platinum/iridium wire [1]. The relative stiffness of Pt/Ir wire with respect to nerve tissue causes slow migration of the electrode within the nerve and eventual encapsulation by fibrous tissue. We are exploring alternate materials for constructing ultra-flexible intrafascicular electrodes. Because of their rope-like molecular structure, polymer microfibers offer greatly improved flexibility over metal wires while maintaining comparable tensile strengths. In this study we quantified the flexural properties of several kinds of fine metal wires, and of fibers made from intrinsically conductive polymers and non-conductive polymer fibers which had been metallized to produce adequate conductivity.

II. MATERIALS AND METHODS

Wire and insulation combinations tested included Pt/10%Ir insulated with Teflon, and pure platinum insulated with Isonel, (AM-Systems, Redmond WA), gold insulated with silicone (PI Medical, Portland, OR) and nickel (H.P. Reid Inc., Neptune, NJ).

Intrinsically conductive fibers composed of pure polyaniline (PANI), blended polyaniline/polyethylene (PANI/PE) [2] and blended polythiophene/polyethylene (POT/PE) [3] were obtained from Uniax Corporation, Santa Barbara CA. Blending conductive polymers with PE greatly improves the mechanical properties of the resultant fibers.

Monofilament fibers of Kevlar, (Kevlar-49, Dupont) and two sizes of nylon sutures (Ethilon, Ethicon Inc.) were metallized via sputtering (Materials Research Corporation). A 300Å thick adhesion-promoting layer of titanium/tungsten was first deposited followed by a 1000Å layer of platinum. This process produced a conductive layer that could withstand simple tape peel tests and cyclic fatigue testing. Conductivity data for all wires and fibers is presented in Table I.

TABLE I

Fiber	Diameter (μm)	Resistance (kΩ/cm)
Platinum	25	0.002
Platinum/Ir	25	0.004
Gold	20	0.0008
Nickel	10	0.009
Polyaniline	80	1.5
PANI/PE	35	45.4
POT/PE	20	14.8
Kevlar/platinum	13	2.0
10-0 Ethilon/platinum	20	1.2
11-0 Ethilon/platinum	16	1.6

Flexural tests were performed according to an adaptation of ASTM D747-90 using a Cahn Model 2000 electrobalance. Duplicate measurements were made for each of two samples of each material. Bending velocity was held constant at 4°/min for all tests.

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III. RESULTS

Results are presented in terms of absolute fiber flexibility computed as the moment required to cause a 7.5° deflection, and the apparent flexural modulus computed according to:

$$E_{flex} = R_{curv} * \frac{M_{bend}}{I}$$

The results are presented in Table II. In general, the non-intrinsically conductive polymer fibers were the most flexible even after metallization which increased fiber stiffness only slightly. The intrinsically conductive fibers were slightly stiffer as a group, but still much more flexible than the Pt and Pt/Ir wires. Gold demonstrated quite good flexibility, and nickel, despite the fact that it had the highest flexural modulus of all materials tested demonstrated excellent flexibility due to its small diameter. Because of the fourth power dependence upon radius, fiber size is a far more important contributing factor to flexibility than is flexural modulus.

TABLE II

Fiber Type	Moment@ 7.5° deflection (μg-cm)	Flexural Modulus (GPa)
Metal wires:		
nickel	53.1 ± 0.01	25.54 ± 0.02
gold	182.5 ± 30.0	4.84 ± 0.79
gold/silicone	718.5 ± 10.1	0.07 ± 0.00
platinum	1937.8 ± 25.4	21.05 ± 0.28
Pt/Isonel	1821.4 ± 12.9	12.57 ± 0.09
Pt/10%Ir	1458.8 ± 6.7	15.84 ± 0.07
Pt/Ir/PTFE	1579.8 ± 14.0	8.27 ± 0.07
Metallized polymers:		
11-0 Ethilon	10.3 ± 1.6	0.67 ± 0.10
11-0 Ethilon/Pt	13.3 ± 2.5	0.86 ± 0.16
10-0 Ethilon	63.1 ± 5.5	1.67 ± 0.15
10-0 Ethilon/Pt	82.8 ± 10.9	2.20 ± 0.29
Kevlar	32.5 ± 2.4	4.82 ± 0.35
Kevlar/Pt	35.4 ± 1.3	5.27 ± 0.20
Intrinsically conductive polymers:		
PANI/PE	184.2 ± 70.8	0.52 ± 0.20
POT/PE	89.1 ± 19.1	2.36 ± 0.51
polyaniline	862.9 ± 0.4	0.09 ± 0.00

IV. DISCUSSION

Conductive polymers hold promise as novel electrode materials, but more work needs to be done to improve both their conductivity and their mechanical properties before really useful electrodes can be made from them. In a preliminary study we have performed implants of polyaniline fiber into cat radial nerve and have been able to record neural signals. Also, in preliminary tests of biocompatibility, polyaniline powder produced less than 1% hemolysis. However, the brittleness of pure polyaniline fibers makes them unsuitable for chronic implantation. And, although mechanically excellent, the conductivity of the polyaniline and polythiophene blended fibers was insufficient for recording.

Very thin metallization layers can impart useful levels of conductivity to non- conductive fibers without greatly affecting the mechanical properties of the fibers. We are currently working on methods for evaluating and optimizing the adhesional characteristics of these metal layers and will shortly begin studies involving chronic implants.

REFERENCES

1. T. Lefurge, E. Goodall, K. Horch, L. Stensaas and A. Schoenberg, "Chronically implanted intrafascicular recording electrodes," *Annals of Biomedical Engineering*, vol. 19, pp. 197-207, 1991.

2. Y. Cao, P. Smith and A. J. Heeger, "Counter-ion induced processibility of conducting polyaniline and of conducting polyblends of polyaniline in bulk polymers," *Synthetic Metals*, vol. 48, pp. 91-97, 1992.

3. J. Moulton and P. Smith, "Gel Processing of Electrically Conductive Blends of Poly(3-octylthiophene) and Ultrahigh Molecular Weight Polyethylene," *J. Polymer Sci*, vol. 30, pp. 871-878, 1992.