

Spinal Cord Microstimulation: Long-term Stability of Implanted Wires and Evoked Responses

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In previously conducted acute experiments, it was shown that spinal cord microstimulation (SC μ stim) can generate functional limb movements in cats: SC μ stim can selectively activate individual muscle groups, produce smooth and graded muscle contractions and reduce muscle fatigue [1-3]. Since March 1998 we have been developing a chronically implantable SC μ stim system. The goal of the work is to determine the long-term stability of muscle contractions produced by stimulating motoneurons and interneurons in the mammalian lumbo-sacral spinal cord. The intended clinical goal is to improve motor function in individuals with spinal cord injuries and hemiplegia through SC μ stim.

Arrays of 6-20 microwires of varying diameter (17-50 μ m) and stiffness were implanted in the lumbo-sacral spinal cord of 12 adult, intact cats for up to 6 months. The loose wires in each array were pre-bent (3.0–4.5 mm lengths, insulated except for 30-100 μ m at the tip) and temporarily held in a silastic gig (spaced 1-3 mm apart), which allowed each to be inserted separately. This had the advantage of causing minimal dimpling to the cord and allowing adequate flexibility in positioning. After insertion, the connecting portions of the microwires lay in an orderly array flush with the dural surface. Plastic film glued over the wires prevented regrowth of muscle, avoiding dislodgement of wires over time [4]. Post-mortem dissections indicated that electrode tips were usually close to their ventral horn target, though their localization could still be improved [4].

Stimulation through single wires (10-300 μ A, 300 μ s, 2-50 pps) generated three types of responses: movements about one joint (60% of wires), whole-limb synergistic movements involving the hip, knee and ankle (30%), and cocontraction of mutually antagonistic muscles causing stiffening of one or more joints (10%). Torques generated in the first two types of responses were large enough to lift the animals' hindquarters (i.e., load-bearing) [4].

Throughout the duration of testing stimulus thresholds and evoked responses remained constant [4]. Stimulus threshold for all microwires doubled after the first 10 days of implantation but remained stable thereafter. This initial increase in threshold was attributed to electrode encapsulation, a product of the natural immunological reaction to implanted foreign objects [4]. The stability of stimulus thresholds following the initial increase indicates that the microwires were remaining securely in place and were not inducing an ongoing inflammatory reaction. At least 67% (67 – 100%) of the microwires implanted in each animal continued to activate the same muscle(s) throughout the duration of testing [4].

The cats were unconstrained in their activities of daily life, so the stability of microstimulation over many months indicates that the method of fixation and strain relief was effective. This should dispel any lingering doubts about the stability of microwire arrays implanted in the spinal cord and the suitability of evoked responses for neuroprosthetic applications.

Accelerated *in vitro* wire corrosion testing was performed on 25-40 μm platinum-iridium (Pt-Ir) and stainless steel (SS) wires insulated except for 30-100 μm at the tip. Each of the wires was placed in a separate saline (0.9% NaCl) bath and a multistrand SS 316 wire in each bath served as the reference electrode. Constant-current, biphasic pulses (300 μA amplitude, 100 μs duration) were delivered at a rate of 125-500 pps through each of the wires 24 hrs/day. The impedance of the wires was periodically measured.

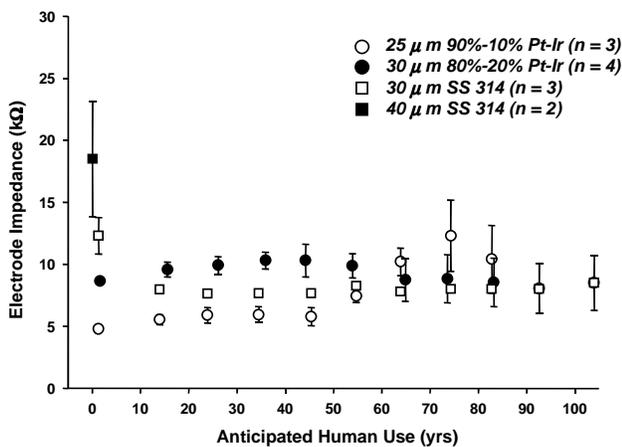


Figure 1: Accelerated In Vitro Wire Corrosion Testing. Microwire impedance (Mean \pm SEM of measurements grouped in 10-yr bins) is plotted against anticipated duration of human use. Both 40 μm SS wires corroded within the first 3 months of anticipated use (filled square symbol). Similarly, two of the three 30 μm SS wires (first open square symbol) corroded within the first 3 months of use. The third 30 μm SS wire (remaining open square points) and all Pt-Ir wires survived more than 100 years of anticipated human use.

Figure 1 tracks the changes in microwire impedance over time. The *in vitro* stimulation time is expressed in terms of anticipated human use time. This conversion was based on an anticipated human use of 4 hrs/day with stimuli delivered at a rate of 50 pps. Four of the five SS wires corroded within the first 4 days of testing (i.e., within the first 3 months of human use). The impedance of the fifth SS and all Pt-Ir wires remained constant throughout the five

month-duration of testing. These results demonstrate that the Pt-Ir microwires can survive more than the equivalent of 100 years of human stimulation. We therefore conclude that Pt-Ir may be a suitable wire for long-term SC μ stim in human subjects.

In summary, the long-term stability of implanted microwires and evoked responses, the suitability of evoked responses for generating functional weight-bearing movements such as standing and walking and the long-term durability of Pt-Ir microwires suggest that SC μ stim is feasible for human applications. Therefore, the first human trials may be conducted sooner than anticipated.

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REFERENCES

- [1] V. K. Mushahwar and K. W. Horch, "Proposed specifications for a lumbar spinal cord electrode array for control of lower extremities in paraplegia," *IEEE Trans Rehab Eng*, vol. 15, pp. 237-243, 1997.
- [2] V. K. Mushahwar and K. W. Horch, "Selective activation of muscles in the feline hindlimb through electrical microstimulation of the ventral lumbo-sacral spinal cord," *IEEE Trans Rehab Eng*, vol. 8, pp. 11-21, 2000.
- [3] V. K. Mushahwar and K. W. Horch, "Muscle recruitment through electrical stimulation of the lumbo-sacral spinal cord," *IEEE Trans Rehab Eng*, vol. 8, pp. 22-29, 2000.
- [4] V. K. Mushahwar, D. F. Collins, and A. Prochazka, "Spinal cord microstimulation generates functional limb movements in chronically implanted cats," *Exp Neurol*, vol. in press, 2000.