Acute and Chronic Neurostimulation Transcutaneously and through Interconnectable, Implantable Waveform Generators

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Introduction

- Temporarily placed percutaneous trial leads are used to assess a patient's response to implanted neuromodulation therapies
- Patients who benefit during the trial period require removal of their working trial lead to allow for a subsequent replacement with a permanent system
- Removal and replacement of a working lead represents a potentially unnecessary surgical burden for patients.
- In addition, successful trial periods do not necessarily predict long term success of their permanent replacements

To reduce the burden of transitioning from a trial to permanent lead, we present a fully needle-injectable helical wire structure electrode (HWSE).

This electrode facilitates a trial period which may then be followed by a straightforward conversion to a chronic therapy through

1) Electrode-augmented transcutaneous stimulation (ATENS), or 2) Attachment to implantable pulse generators (IPGs) / receivers as demonstrated in rodent sciatic nerve stimulation models and cadaver models.

Methods

- HWSEs (PtIr, polyolefin) were manufactured (Neuronoff, Cleveland OH) with or without IPG connectors (316-SS, PE)
- Rodents (CD-1, Sprague-Dawley, Charles River, Durham NC) were injected with HWSEs (per CWRU IACUC approved protocols) on their right sciatic nerve.
- Plantar flexion thresholds, ankle torques, joint angles, and superficial "off-target" muscle contractions at the stimulation site were measured at timepoints from 0-8 weeks post-implant in response to current and voltage sweeps (Twin-Stim+, 30Hz, 300µs and DS7A, Digitimer, 30 Hz, 500µs) applied transcutaneously via adhesive patches (Cadwell, Ambu-Neuroline).
- HWSEs with connectors were injected to dorsal root ganglia in human cadavers prior to connecting with IPGs under fluoroscopy.
- HWSEs with connectors were implanted for up to 6 months (rat) prior to connecting and stimulating with rIPGs under fluoroscopy.

Results

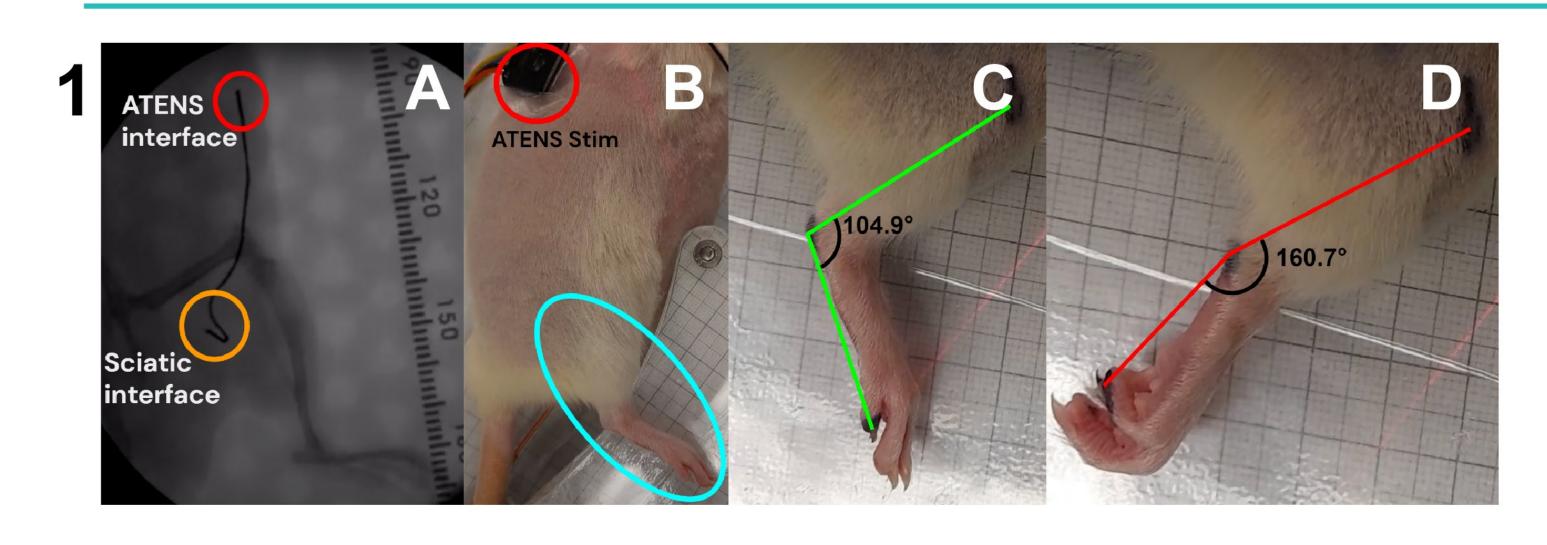


Figure 1A. Helical wire structure electrode as delivered to rodent sciatic nerve under fluoroscopic guidance. A 'collector' (red) is placed subcutaneously near the thoracic cage, ~7 cm distal from the active nerve interface (orange).

Figure 1B/C/D. Stimulation is applied above the collector using a surface patch. Changes in the joint angle formed by the knee joint, ankle joint, and metatarsal head, are measured in response to current and voltage ATENS of the sciatic nerve.

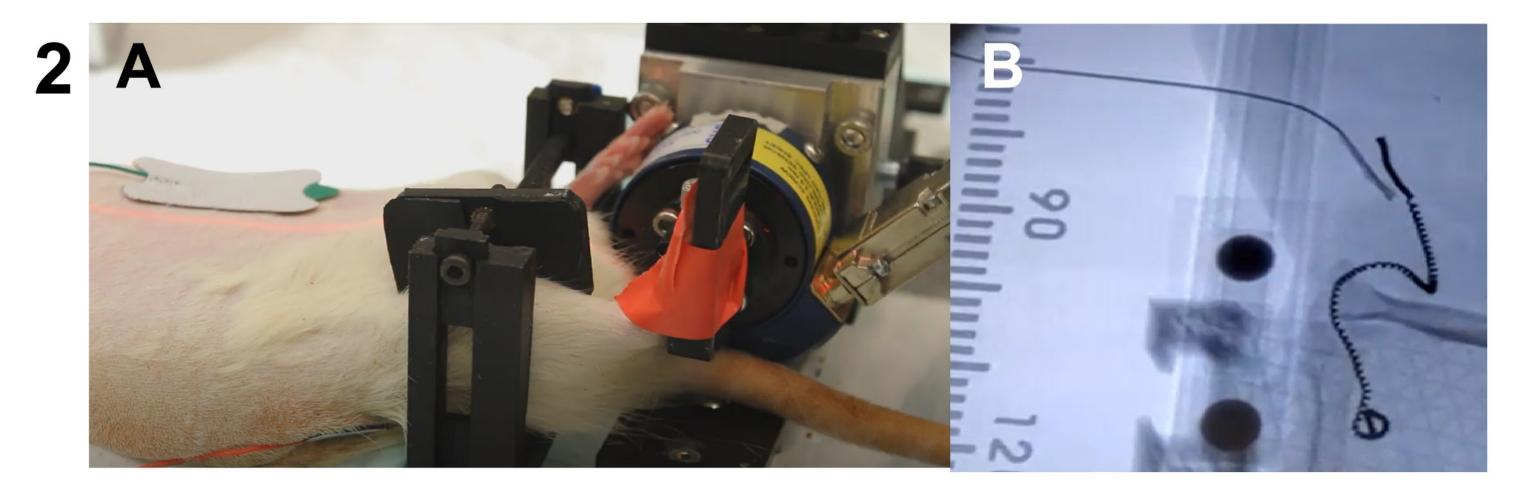


Figure 2A. Rodent right hindlimb fixed to a foot pedal attached to a 6-DOF force transducer for quantitative torque assessment. Rodent knee is fixed by clamp to reduce extraneous movement.

Figure 2B. ATENS stimulation with rodent hindlimb in the apparatus performed by overlying patch electrode with uncoated subcutaneous 'collector' under fluoroscopic guidance for confirmation.

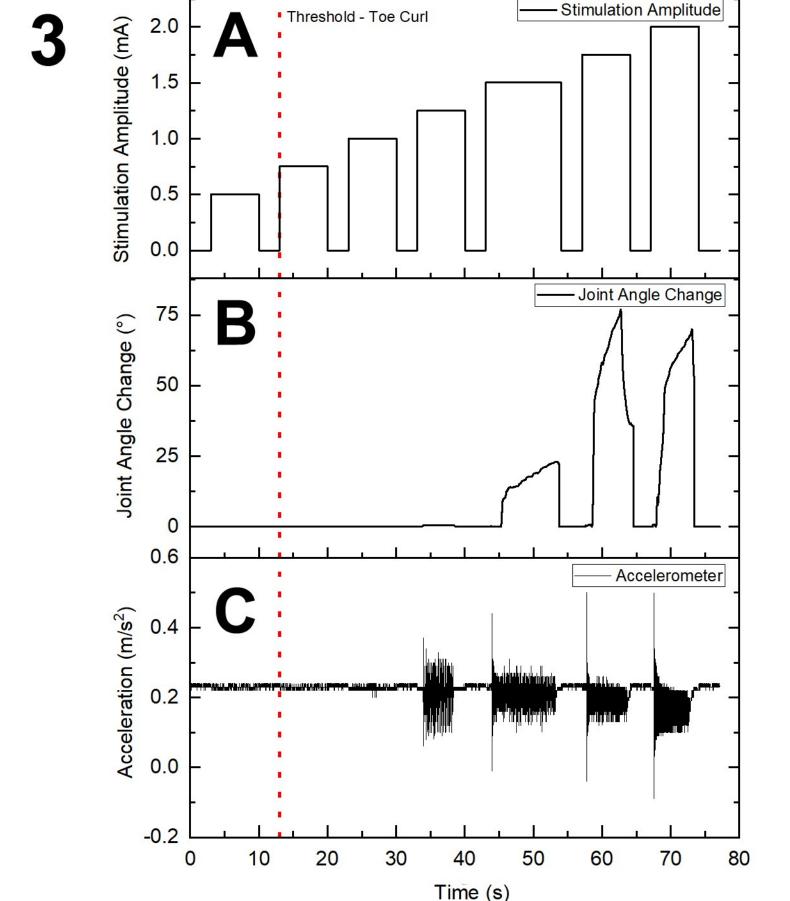


Figure 3A/B/C. Example sciatic stimulation evoked angle changes with concurrent measurement of superficial cutaneous (off-target) activity via accelerometer laid atop stimulation site.

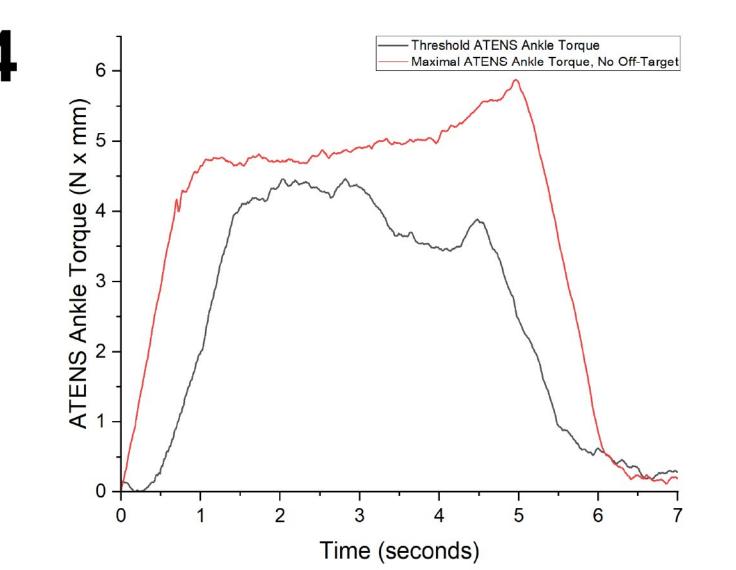


Figure 4. ATENS torque measurements at threshold and maximal surface stimulation amplitudes prior to presence of off-target superficial fiber activation.

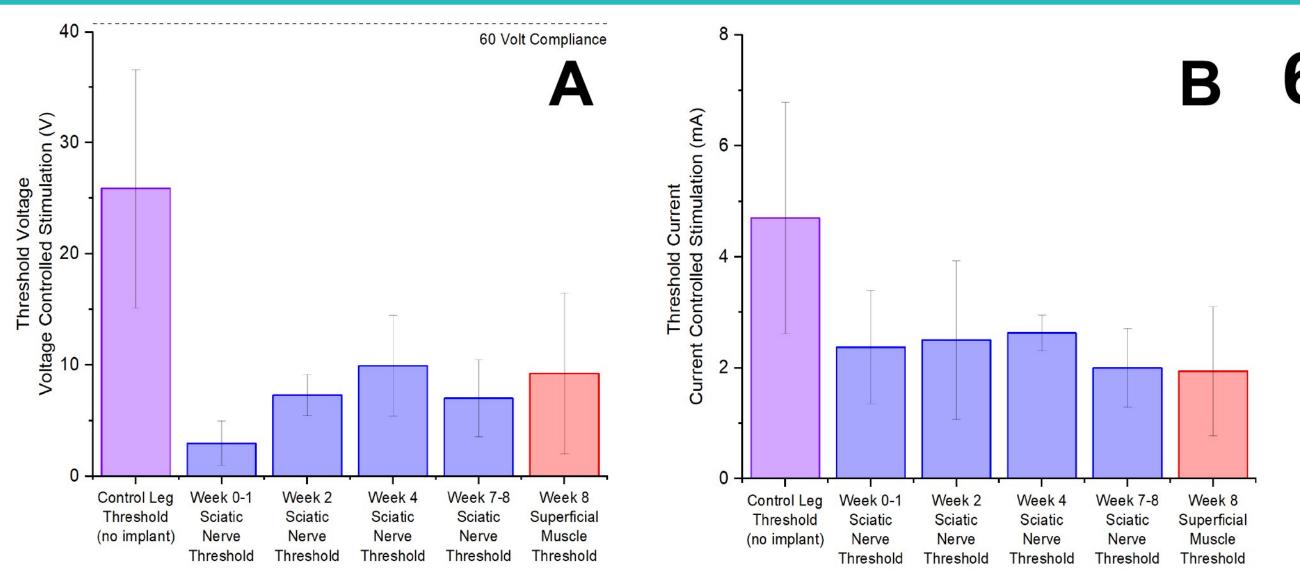
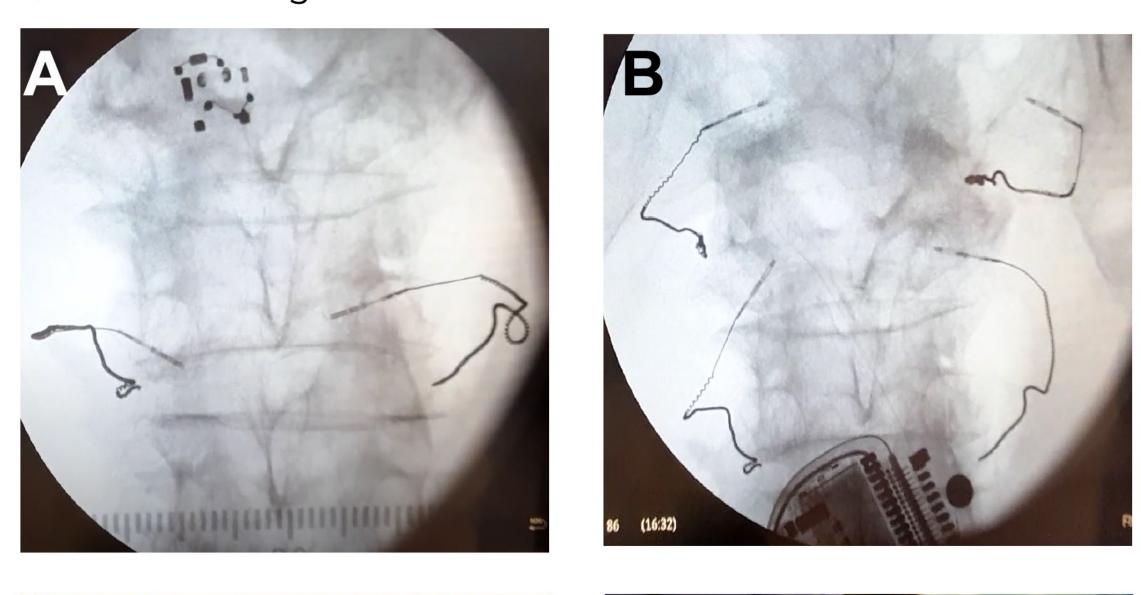


Figure 5A/B. ATENS current (DS7A, current-controlled) and voltage (Twin-Stim, voltage-controlled) thresholds show sciatic nerve and superficial activation at post-implant and chronic follow-ups. Control (contralateral) thresholds reflect stim. at the collector site prior to placing HWSE to achieve leg motion.



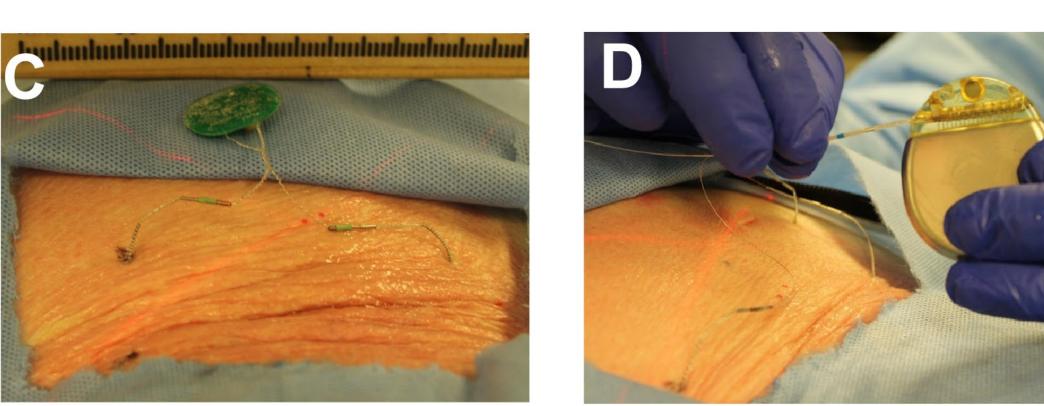


Figure 7. Helical wire structure electrodes injected onto dorsal root ganglia in human cadaver, attached to custom resonance IPG (A, C) and standard IPG (B, D) via connector attachments.

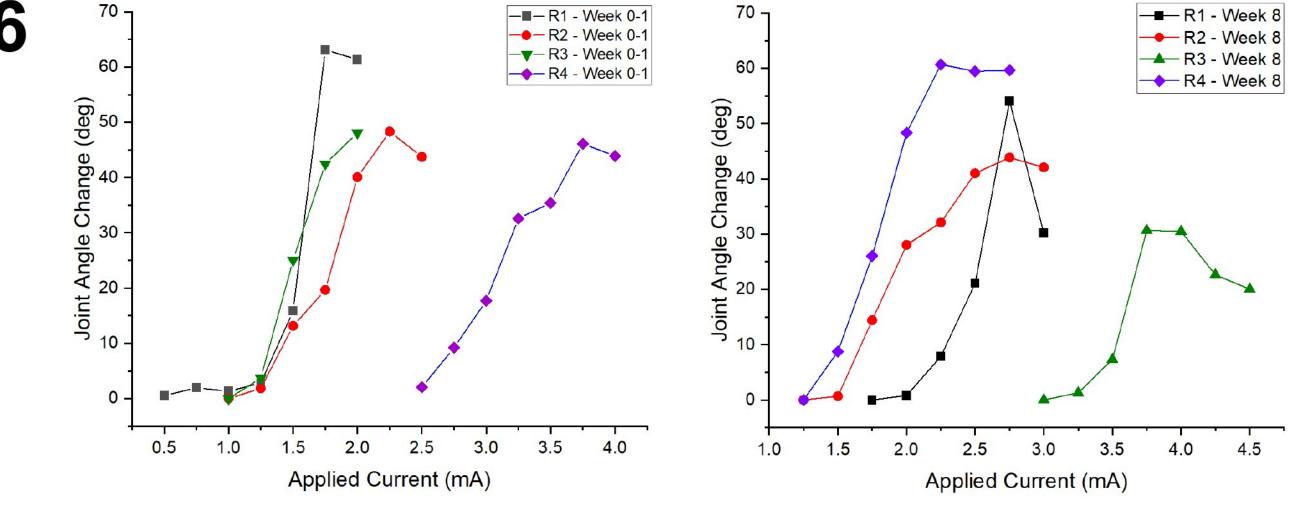


Figure 6A/B. Compiled (n = 5) change in joint angle versus applied current (mA) shows increasing recruitment at higher currents (Week 1 to Week 8).

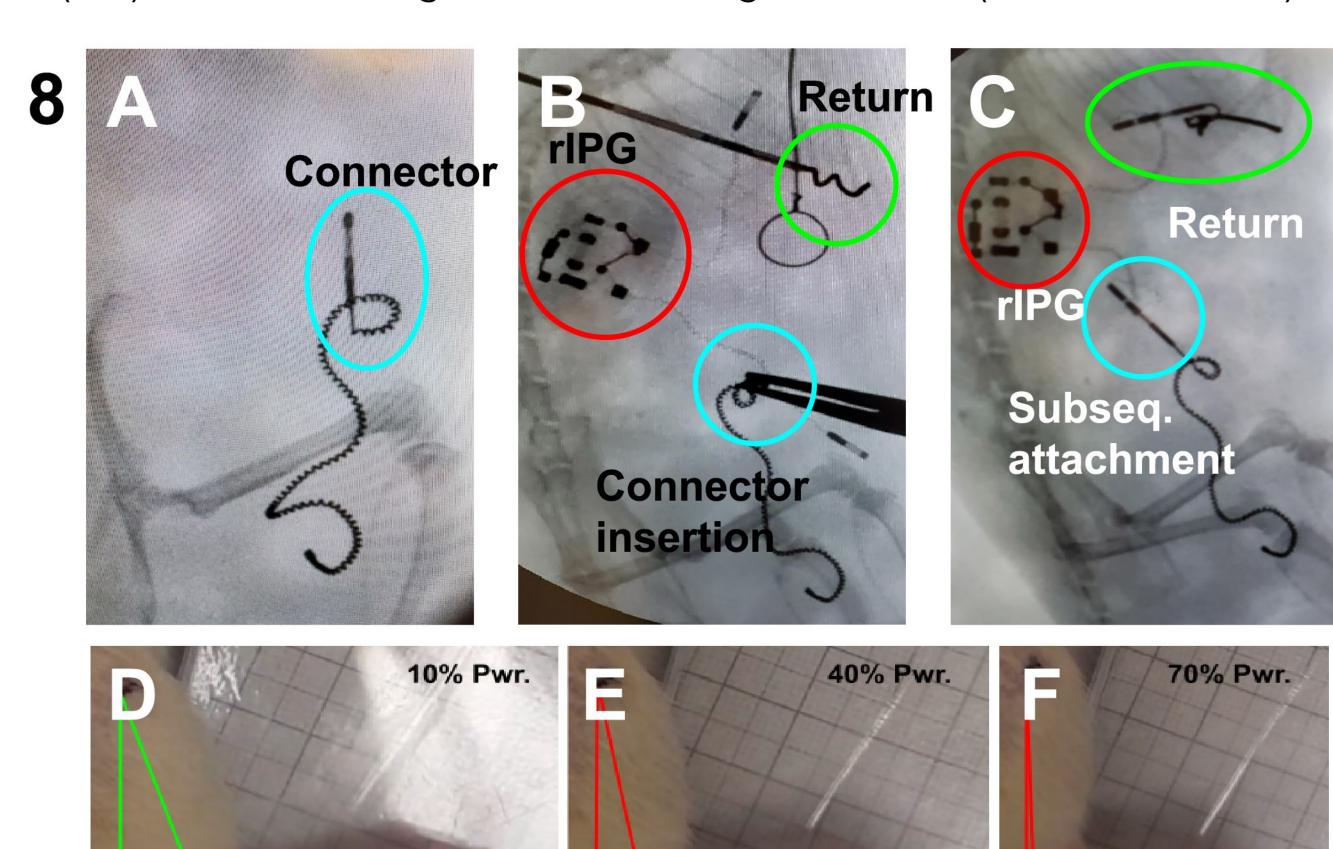


Figure 8A/B/C. An electrode injected with connector attachments (blue). Subsequent surgery (+2mo.) is done to connect a custom rIPG (red) to the previous implant as well as a distal return electrode (green).

Figure 8D/E/F. Stimulation (charge-balanced, biphasic) through inductive coupling by programmable driver (20 - 4000 Hz, 220 - 2800µs PW) produces joint movement.

Conclusions and Future Directions

- HWSEs are transcutaneously efficacious for sciatic nerve stimulation, shown via induced joint angles (to 63°) and torque (to 6 Nmm).
- ATENS produced plantar flexion thresholds ranging from 1.25 to 3.70mA and 0.60 to 6.90V upon implanting, 12x lower than V compliance (60V). Thresholds on average doubled at 4-8 week follow-ups, but remain achievable while generating minimal superficial cutaneous activity.
- Connectors enabled follow-on attachments of HWSE to stimulation capable IPGs in relevant cadavers and after chronic ATENS
- Future studies will further establish the envisioned clinical implementation of the HWSE as a trial lead for neuromodulation therapies

Acknowledgements

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