Towards Optimized Neural Stimulation in a Device for Urinary Incontinence

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Abstract

Introduction
The periodic storage and elimination of urine depend upon coordinated signalling of the peripheral nervous system which is organized in the brain and spinal cord. After spinal cord injury (SPI) the functions of the lower urinary tract are often disrupted and may have fatal consequences for the patient.

Using the probe shown in Figure 1, Craggs et al. [1] in their study on 6 SPI patients, suffering from relevant conditions, demonstrated that by conditional trans-rectal stimulation of the pudendal nerve upon sensing an adequate electromyographic signal from the external anal sphincter, it was possible to suppress hyper-reflexive contractions of the bladder and increase the bladder capacity in all the subjects.

To offer a disruptive solution based on this concept, it is necessary to embed microelectronics and a rechargeable battery in a probe similar to the one shown in Figure 1 to make an autonomous device. However, as the stimulation of the nerve is carried out trans-rectally, a high level of current is required to excite the nerve. Therefore, it is necessary to make sure that the electrodes on the probe and the current injection method are optimally configured to deliver a minimum amount of charge to achieve the required level of excitation. Moreover, to reduce the maximum voltage compliance required for the electronics, different configurations should be investigated.

Use of COMSOL Multiphysics®
To define the trajectory of the targeted nerve with the probe in situ, a set of magnetic resonance imaging scans where taken as shown in Figure 2 and an approximate trajectory of the nerve was defined.

A 3D model of the probe was developed using COMSOL Multiphysics® software as shown in Figure 3. The surrounding medium was set as water and was divided into 2 sections as shown in Figure 3. The immediate area around the probe was set to have a conductivity of 0.4 S/m and the conductivity of the rest of the medium was set to 0.8 S/m based on the experimental data [2] and literature [3]. Eight stainless steel electrodes were defined on the surface of the probe to investigate different stimulation configurations. The approximate trajectory of the nerve was defined as a "Cut Line 3D" for further analysis.

Results

It has been shown that positive second spatial derivative of the extracellular electric potential in the direction of the nerve (activating function) indicates that an action potential can be generated inside the nerve [4]. Different stimulation configurations were simulated while setting 50 mA to pass through the cathode and the anodes were set as ground. A summary of some of the results including the voltage profile, activating function, and the area under activating function curves are presented in Figure 4.

Conclusion

It is obvious from the results that the configuration (C, A3, A4) presents a considerably more positive activating function. By ignoring the nerve trajectory variations in different individuals, it is possible to assume that the aforementioned configuration can excite the nerve at a lower threshold while offering lower voltage compliance for the electronics.

Reference

[1] M. Craggs et al. “Conditional neuromodulation using trans-rectal stimulation in spinal cord injury,” 2009.

[2] A. Shiraz et al. “Towards an optimized wearable neuromodulation device for urinary incontinence,” in Electronics, Circuits and Systems (ICECS), 2012 19th IEEE International Conference on, 2012, pp. 25–28.

[3] S. Gabriel et al. “The dielectric properties of biological tissues: Iii. parametric models for the dielectric spectrum of tissues,” Physics in medicine and biology, vol. 41, no. 11, p. 2271, 1996.

[4] F. Rattay, “Analysis of models for external stimulation of axons,” Biomedical Engineering, IEEE Transactions on, no. 10, pp. 974–977, 1986.

Figures used in the abstract

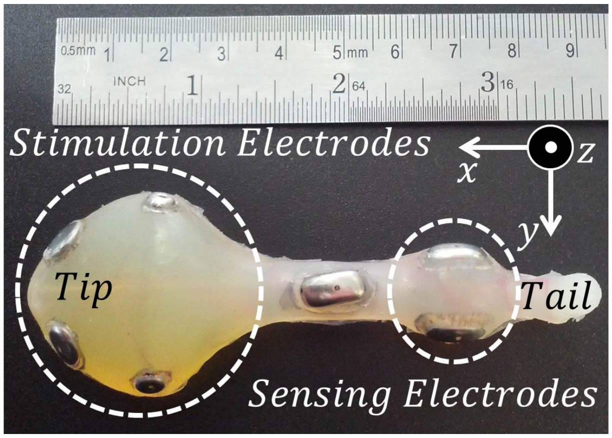


Figure 1: The ano-rectal probe used for the proof-of-concept study and preliminary studies.

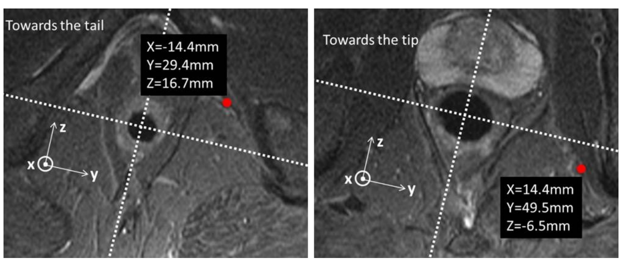


Figure 2: MRI images of the pelvic area, indicating 2 points where the nerve passes. Multiple tissue layers and the relative position of the nerve with respect to the device can be seen.

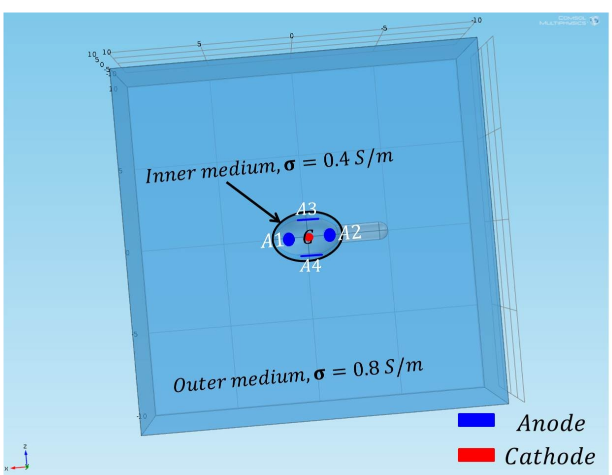
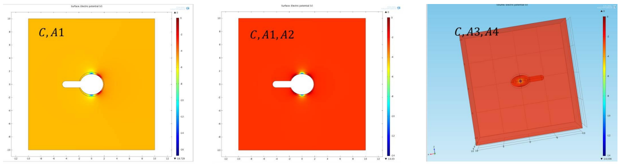
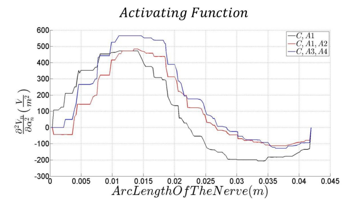


Figure 3: A 3D model of the device with extra eletrodes defined on the surface of the device to investigate different stimulation configurations.





Configuration	Area under the curve (V/m)
C,A1	3,7229
C,A1,A2	5,2020
C,A3,A4	7,3954

Figure 4: Summary of the results including the voltage profile in 3 different configurations, activating function along the nerve, and the area under the activating function curve.