Swine pudendal nerve intraneural stimulation enables selective neuromodulation of urethral and anal external sphincters

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Lower urinary tract dysfunctions, leading to incontinence or urinary retention, profoundly impair quality of life. Current neuromodulation therapies, such as sacral or posterior tibial nerve stimulation, typically rely on lead or needle electrodes that lack selectivity, i.e. the capability to precisely stimulate portions of the nerve, often causing off-target effects and limiting efficacy.
To address this limitation, we investigated Transverse Intrafascicular Multichannel Electrode (TIME) in the pudendal nerve of the swine, a relevant model for urinary tract neuromodulation studies (Giannotti et al., 2024). The pudendal nerve is a promising alternative to common stimulation sites as it carries afferent signals of bladder filling and efferent commands to the external urethral and anal sphincters, enabling direct modulation of continence and micturition reflex (Ouyang et al., 2022).
In this study, two male farm pigs (Sus Scrofa Domesticus, 35-40 kg, 3-4 months old) underwent transgluteal exposure of the pudendal nerve, followed by implantation of a 16-channel TIME. During the first experiment, the electrode was implanted proximally, about 2 cm before trunk consolidation, whereas in the second it was placed more distally, 1 cm beyond the convergence of sacral contributions. Biphasic, cathodic-first pulses (200 µs width, 10-600 µA, 3 Hz) were delivered, while electromyographic activity from the external urethral sphincter (EUS) and external anal sphincter (EAS) was recorded using needle electrodes. Normalized recruitment curves were derived for each muscle, and selectivity was quantified as their maximum difference, yielding values constrained between -1 and +1 to indicate greater recruitment of the EAS or EUS, respectively.Proximal stimulation selectively recruited the EAS, with all 16 active sites yielding selectivity values between -0.28 and -0.68. In contrast, during distal stimulation only 9 sites were selective for the EAS (-0.11 to -0.87) and the rest for the EUS (+0.54 to +0.57). These findings suggest the presence of a functional fascicular gradient along the pudendal nerve that can be leveraged to selectively modulate key effectors of urinary and fecal continence, highlighting the need for further anatomical and functional studies.
Our results provide a foundation for refined neuroprosthetic strategies targeting lower urinary tract control via the pudendal nerve. Importantly, the high translational potential of these outcomes underscores their relevance for clinical applications in patients with neurogenic bladder or spinal cord injury.