Circumferential Bioelectronics Enable Spinal Cord Recording And Stimulation Bypass Following Spinal Cord Injury

Jiang L[1], Woodington B[2], Carnicer-Lombarte A[2], Güemes-González A[2], Hilton S[2], Malliaras G[2], Barone D[2]
[1]Department of Orthopaedic Surgery, Singapore General Hospital
[2]Bioelectronics Laboratory, University of Cambridge

Introduction/Objectives: Spinal cord injury (SCI) is a disabling neurological condition that can lead to irreversible loss of sensory, motor and autonomic functions. Although advances in spinal cord stimulation (SCS) have enabled the restoration of overground walking in patients with SCI via external triggers, this does not represent the true restoration of the patient's volitional motor activity. To truly achieve a closed-loop electronic bypass of SCI to restore volitional motor activity, recording motor signals proximal to the SCI site is essential.

Materials and Methods: By harnessing advances in thin-film bioelectronic devices that closely match the stiffness of neural tissue, we have designed a non-penetrating conformal bioelectronic array capable of interfacing with the spinal cord circumferentially without causing iatrogenic SCI. In this exploratory in vivo study, we firstly implanted the electrode array epidurally around the spinal cord at the T10 vertebral level in adult female rats (Sprague-Dawley, n=16) and recorded the compound action potentials evoked by stimulation of the motor cortex (motor evoked potentials (MEP)) and sciatic nerves (somatosensory evoked potentials (SSEP)). Secondly, to functionally bypass a site of SCI, we implanted recording and stimulation electrode arrays at the T10 and L1 vertebral levels respectively and excised the spinal cord in between. We then produced a low-latency communication between the 2 arrays using a threshold detection method.

Result/Discussion: Firstly, we have demonstrated that flexible bioelectronic arrays can be implanted around the spinal cord without causing iatrogenic SCI, enabling comprehensive recording of epidural neural signals circumferentially. These signals can be represented in a topographic heatmap, enriching the analysis of electrophysiological data in both the time and spatial domains. The unique topographic heatmap signatures enabled machine learning modelling of channel activity following SSEP and MEP, achieving 93.5% classification accuracy of stimulation source. The topographic resolution proved sufficient to accurately classify SSEP from sciatic nerve branches with an accuracy of 100%. Secondly, we capitalized on the recorded spinal cord signals to serve as stimulation triggers for spinal cord stimulation using a low-latency communication between 2 arrays above and below a site of SCI. This enabled the recording array to detect the peak of an MEP in response to motor cortex stimulation and trigger the stimulating array to effect hindlimb movement in paralyzed rats.

Conclusion: In this proof-of-concept study, we have demonstrated that interfacing circumferentially around the spinal cord enables the comprehensive spatiotemporal representation of neural signals. This approach represents the next generation of spinal cord neural interfaces, showing that closed-loop bypass of SCI is feasible and can one day restore volitional motor function to patients with paralysis.