Dermal-Based Peripheral Nerve Interface for Transduction of Sensory Feedback

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INTRODUCTION: We developed a Dermal Sensory Interface (DSI) with the long-range goal of providing high fidelity perception of somatosensory feedback from prosthetic limbs. DSIs consist of small de-epithelialized skin grafts placed subcutaneously that are reinnervated by residual sensory peripheral nerves. Patterned electrical stimuli are applied to the DSI to excite native mechanoreceptors within the DSI sending action potentials along the residual sensory nerve to the somatosensory cortex for tactile perception. Our immediate purpose is to establish the predictability between graded electrical stimulation and evoked somatosensory feedback signaling in DSI and control skin conditions.

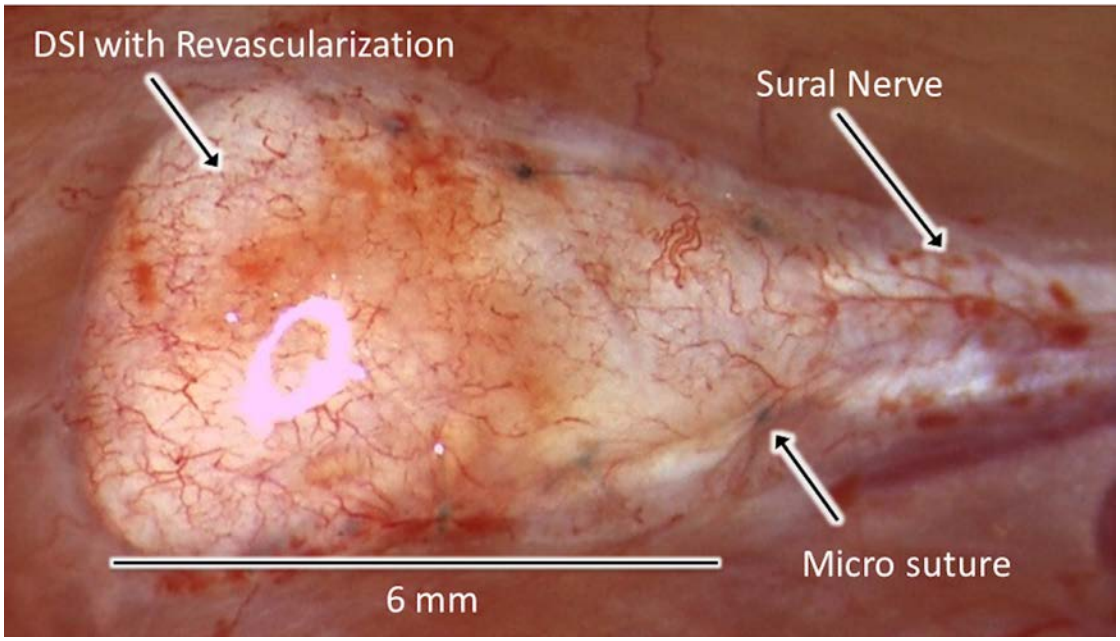
MATERIALS AND METHODS: Using a rat model, de-epithelialized skin grafts were secured around the proximal end of the transected sural nerve in a submuscular pocket; these DSIs were allowed two months for reinnervation (Fig 1). We compared electrophysiological signals recorded at the proximal sural nerve in response to electrical stimulation on DSIs (n=10), native full-thickness skin (n=10), and native de-epithelialized skin (n=10). Measurements included threshold stimulation current to evoke compound sensory nerve action potentials (CSNAPs), percent CSNAP elicitation at 10, 20, 50, and 100 Hz stimulation frequencies, and sural nerve potential in response to graded stimulation current.

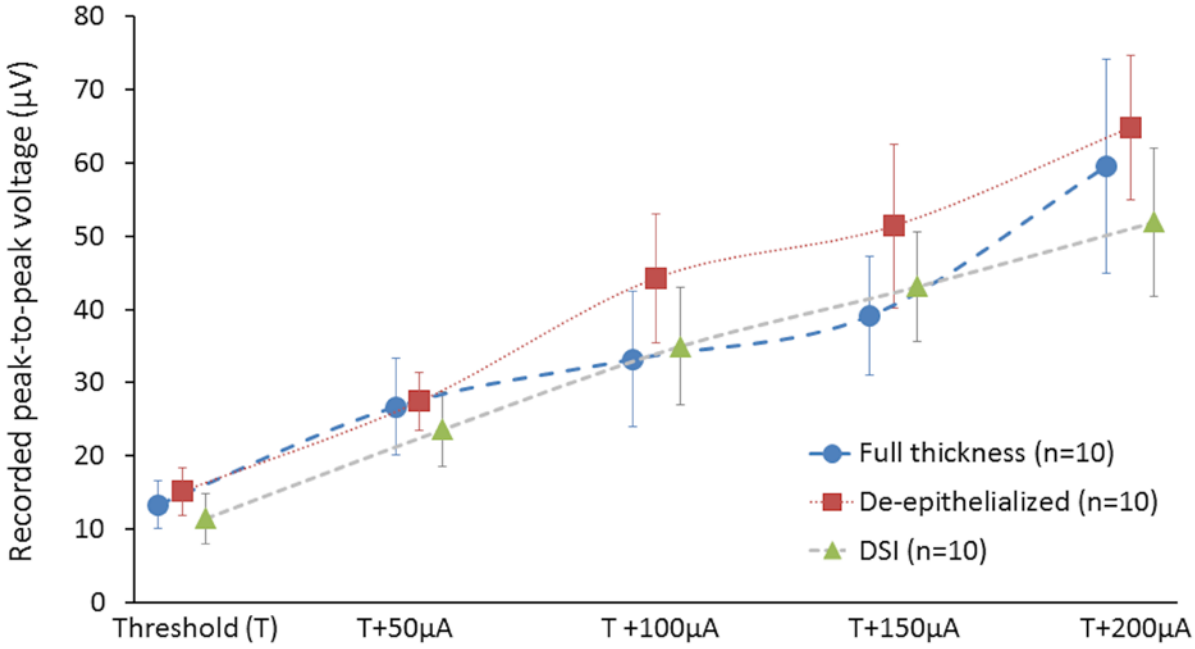
RESULTS: Electrical stimulation of DSIs reliably elicited CSNAPs. Stimulation current thresholds to evoke CSNAPs for DSIs (465 ± 110 μA) were similar to those for full thickness skin (600 ± 281 μA, $p = 0.17$) and de-epithelialized skin (594 ± 186 μA, $p = 0.8$). Over 96% of pulses delivered at 100 μA above current threshold to DSIs elicited CSNAPs at frequencies less than or equal to 100Hz. CSNAP potential increased in response to increased stimulation current similarly for DSIs, full-thickness skin, and de-epithelialized skin (Fig. 2). Histomorphometric analysis of DSI tissue revealed healthy dermis with minimal inflammation and no evidence of neuroma.

CONCLUSION: Stimulation current thresholds to evoke CSNAPs were similar between DSIs and native skin. Elicitation of CSNAPs was reliable even at high stimulation frequencies. Varying the stimulation current applied to DSIs produced differential CSNAP potentials characteristic of native afferent signaling amplitudes. These findings suggest that patterned electrical stimulation can be successfully transduced across DSIs to produce graded sensory feedback.

FIGURE LEGEND:
Figure 1. Dermal Sensory Interface (DSI) *in vivo* two months after fabrication.

Figure 2. Mean +/- SEM peak-to-peak sural nerve CSNAP amplitude (μV) in response to incremental increase in stimulation current (μA) above threshold when pulsed stimuli were delivered at 20 Hz.


DSI with Revascularization
Sural Nerve
Micro suture
6 mm


Recorded peak-to-peak voltage (µV)
80
70
60
50
40
30
20
10
0
Threshold (T)
T+50µA
T +100µA
T+150µA
T+200µA
Full thickness (n=10)
De-epithelialized (n=10)
DSI (n=10)