Modeling of transcutaneous spinal cord stimulation

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TRANSCUTANEUS electrical spinal cord stimulation (SCS) is a non-invasive method to stimulate afferent structures of the human spinal cord [1]. These are the same target structures as in lumbar epidural SCS [2]. Here, a computer simulation is presented that aims to shed light on why distant skin electrodes selectively activate specific groups of fibers localized in the spinal canal and whether other structures are concomitantly stimulated.

The simulation is conducted in two steps: i) A finite element model of the human trunk, including skin, paraspinal muscles, vertebrae, intervertebral discs, epidural fat, cerebrospinal fluid as well as white and gray matter, is applied to calculate the electric potential generated by skin electrodes placed over the paravertebral muscles and the abdomen. ii) The electric potential evaluated along the trajectories of target neural structures was used as the input for a nerve fiber model [3] and to calculate activating functions [4,5]. Due to the electrophysiological findings [1] and fiber properties (i.e. diameters and myelination) fibers in the posterior root (PR), anterior root (AR) and posterior column (Pcol) of the lumbar spinal cord were simulated [6].

The activating functions show that there are sites of strong depolarization at entrance of the PR fibers in the spinal cord and at the entrance/exits of the PR and AR fibers into/from the spinal canal, while there were no such `hot-spots' for the Pcol fibers (fig. 1). The nerve fiber model confirmed that action potentials are initiated at these low threshold sites. Activation thresholds for the most preferentially located fibers of each class were 14.1 V, 22.6 V and 67.4 V for the PRs, ARs and Pcols. With the addition of 5 collaterals the lowest threshold of any fiber in the Pcols was 45.4 V.

The distant stimulation is due to anatomical properties (axon bends and their transitions of media with different conductivities) that introduce stimulation `hot-spots' [5]. Furthermore, PRs are preferential targets, while co-activation of Pcol fibers is improbable [6].

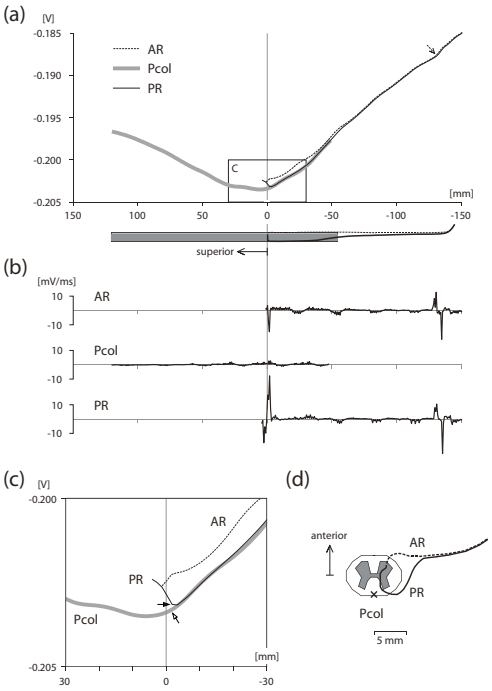

Fig. 1 Stimulation effect evaluated along target nerve structures. (a) Extracellular potential along the three fiber types. The posterior root (PR) and the anterior root (AR) enter and exit the spinal cord, respectively, at the level of the stimulating electrode. The posterior column fiber is located medially and centrally in white matter. (b) Activating functions corresponding to (a). (c) Enlarged view of the box in (a). (d) Topview of the fiber trajectories and the spinal cord (adapted from [6]).

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