Evaluating the Impact of Nerve Anatomy Variation on Peripheral Nerve Stimulation: A Mathematical Model Analysis

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INTRODUCTION

Peripheral nerves vary widely in their anatomy including in their diameter, myelination, location within the nerve, the packing fraction and fascicle distribution. When these nerves are electrically stimulated the anatomical variations can have a significant impact on the thresholds and selectivity on the specific fascicles that are depolarized.

METHODS

We developed a mathematical model of the effective fascicle conductivity to capture the variation in the packing fraction and fiber diameter. Nerve fibers in a fascicle were treated as parallel conductors (Figure 1) to calculate the effective axial conductive for the fascicle as a function of the packing fraction (Figure 2). Simulation experiments were performed to estimate the effective radial conductivity of the fascicle as a function of the packing fraction (Figure 3).

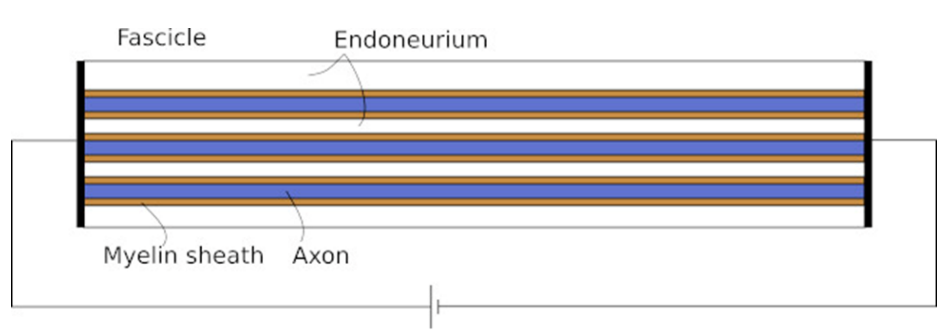

Figure 1: Nerve fibers in a fascicle are treated as parallel conductors to compute the effective axial conductivity for the fascicle as a function of packing fraction.

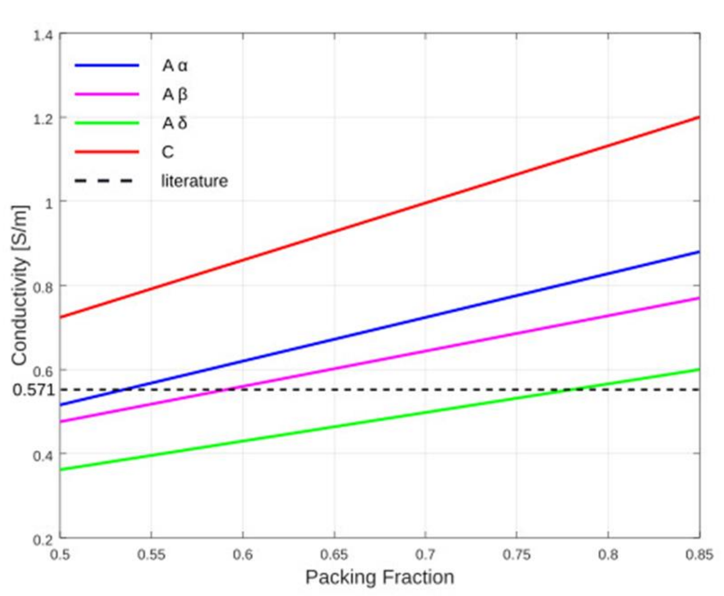

Figure 2: Variation in the effective axial conductivity of a fascicle with respect to packing fraction.

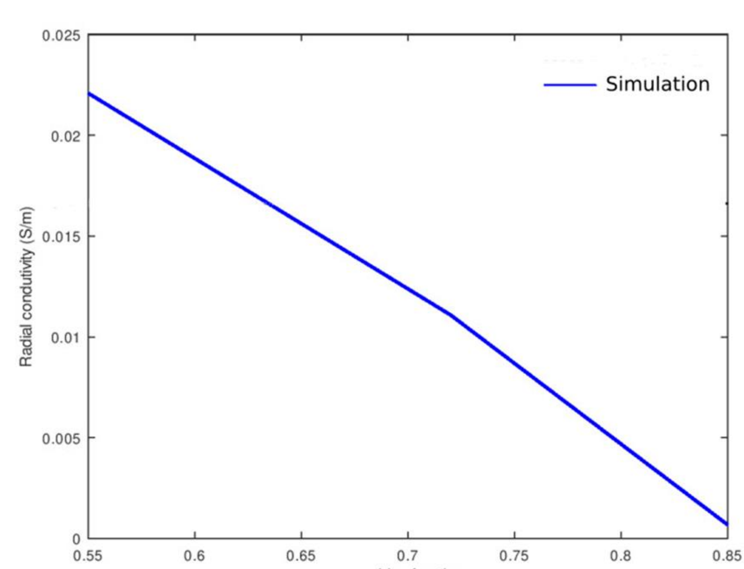

Figure 3: Variation in the effective radial conductivity of a fascicle with respect to packing fraction. The fascicle is modeled to be made up of Aα fibers.

METHODS…

A linear activating function was used as the indicator of generation of an action potential. The distance between the electrode and nerve was changed systematically while evaluating the linear activating function (Figure 4).

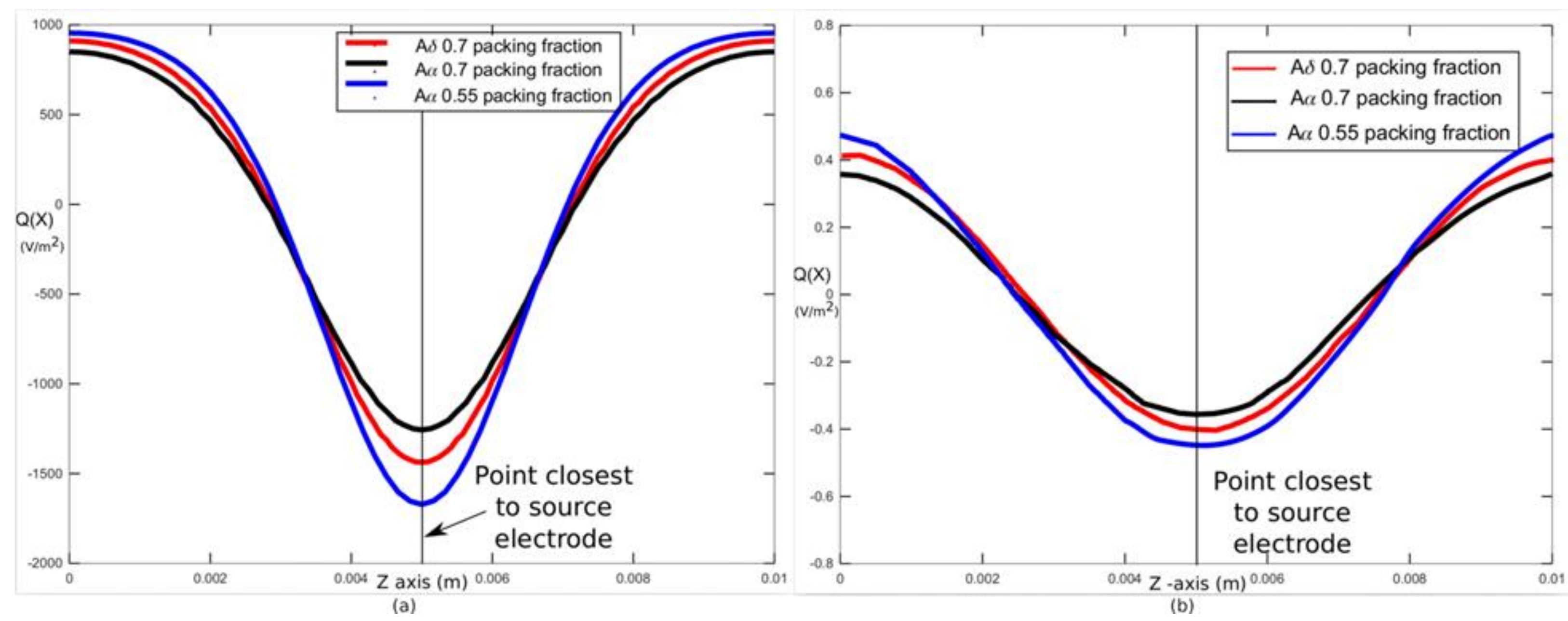

Figure 4: Q(X) is the linear activating function, defined as the second derivative of potential along the length of the fascicle. The plot of Q(X) is compared for three types of fascicles containing different types of fibers The plot on the left corresponds to a configuration where the electrode is placed close to the nerve bundle. The plot on the right (b) corresponds to a configuration where the electrode is placed further away from the nerve bundle.

RESULTS

The studies suggest that placing electrodes close to the nerve results in a skewed profile of current density (Figure 5), indicating the ability of local control over current flow and to steer the current. Thus, placing electrodes close to the nerve could improve stimulation selectivity while minimizing the current expended (Figure 6). The studies also suggest that implanting leads with multiple electrodes may increase the possibility of stimulating the desired target fascicles.

RESULTS…

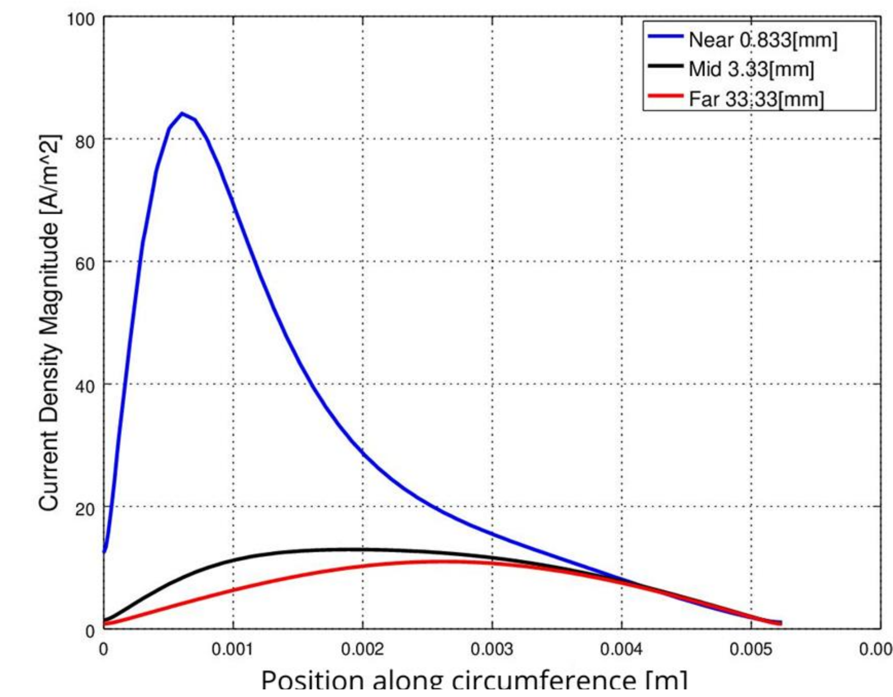

Figure 5: Spatial distribution of current density along the nerve bundle circumference. Three geometry configurations are considered, with the distance between the electrode and nerve bundle changing for each configuration. The spatial variation in current density observed for the Near configuration suggests that placing electrode close to the nerve bundle will improve selectivity.

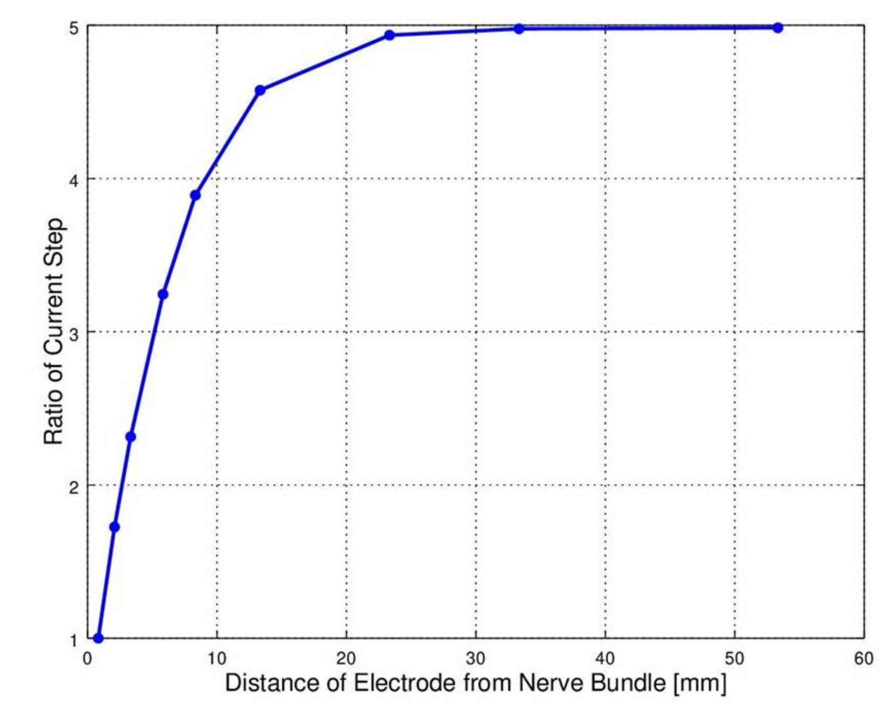

Figure 6: Plot of ratio of current step with respect to distance between electrode and the nerve bundle. The ratio of current step represents the amount of current to be sourced through the electrode to achieve similar amount of current passing through the nerve bundle with respect to a reference distance. The figure indicates that a lower amount of current will be expended when the electrode is placed closer to the nerve bundle.

CONCLUSIONS

A mathematical model analysis was conducted to understand the impact of nerve anatomy variation on peripheral nerve stimulation (PNS). The results suggest that the proximity of electrodes to nerves and the options of multiple electrodes can have significant impact on stimulating desired anatomy. This and future research will guide the design and engineering of more capable PNS neuromodulation systems.

See also: https://doi.org/10.2147/JPR.S380546