RELATIONSHIP BETWEEN PERCEPTION THRESHOLD AND THICKNESS OF THE DORSAL CSF-LAYER IN EPIDURAL SPINAL CORD STIMULATION

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ABSTRACT

We tested the hypothesis that the thickness of the dorsal csf-layer is the main factor determining the perception threshold in dorsal epidural spinal cord stimulation. Therefore, the distributions of the midcervical and the midthoracic csf-layer thickness, measured from MRI scans, were used to calculate the distributions of spinal nerve fiber threshold stimulation in a computer model. The theoretical distributions were compared with the distributions of perception threshold measured in patients. A good fit between the two distributions was found.

INTRODUCTION

Clinical experience in epidural spinal cord stimulation has shown that the mean perception threshold varies as a function of the vertebral level of the electrode and is probably related to the distance between electrode and spinal cord, being the thickness of the dorsal csf-layer [1]. Another indication for this relationship is that both dorsal csf-layer data from an MRI study [2] and perception threshold data (TJU, Philadelphia) have distributions with a positive skewness at all spinal levels investigated. We were able to relate these data by using a computer model for spinal cord stimulation [3–5], by which the lowest threshold stimulus for exciting spinal nerve fibers was calculated for models having various thicknesses of the dorsal csf-layer. In this way we tested whether the distributions of perception threshold at a midcervical and a midthoracic level are related to the corresponding distributions of csf-layer thickness.

METHODS

Measurement of perception threshold

Perception thresholds (Volts) were determined in patients in a supine position, having a spinal cord stimulation system with a Resume electrode (Medtronic Inc., Minneapolis) implanted epidurally for chronic pain management. The electrode has a longitudinal array of four equidistant contacts. Data selected for this study were from dorsomedially placed bipolar combinations of neighboring contacts (6 mm separation) and the cathode at vertebral levels C4–C6 and T4–T7. Pulse width and pulse rate were kept constant (210 μs, 50/s).

Determination of dorsal csf-layer thickness

The thickness of the dorsal csf-layer was measured from transverse MRI scans of volunteers in a supine position at a midcervical and a midthoracic vertebral level [2]. Strongly T2 weighed Turbo Spin Echo scans were used in order to obtain good contrast between spinal cord, cerebrospinal fluid and dura mater.

Calculation of threshold stimuli of spinal nerve fibers

We used a computer model consisting of two parts [3–5].

A 3-dimensional volume conductor model, representing the gross anatomy and electrical conductivities of a midcervical/midthoracic spinal cord segment and surrounding anatomical structures (cerebrospinal fluid, dura mater, epidural fat, vertebral bone), as well as the geometry and position of the epidural Resume contacts. The potential field in the model was calculated by solving the discretized Laplace equation, using the contacts and the outer boundary of the model as voltage sources.

A McNeal type model of myelinated nerve fiber, representing the electrical behavior of a dorsal column (DC) fiber and a dorsal root (DR) fiber in the calculated electrical field. Threshold voltages for the excitation of these fibers were calculated, using a 210 μs rectangular stimulus pulse. The DC-fiber was at the dorsomedial border of the Dorsal Columns, while the DR-fiber had different orientations in the midcervical and the midthoracic models.

RESULTS

MRI data

The thickness of the dorsal csf-layer was measured from series of transverse images at C4–C6 and T5–T6 from 26 healthy volunteers (19–38 years old). At C4–C6 the csf-thickness ranged from 1 to 5 mm (mean=2.5 mm) and at T5–T6 from 3 to 11 mm (mean=5.8 mm). The distributions were skew, as shown for C4–C6 in Fig. 1.

Threshold stimuli of spinal nerve fibers

We made a series of midcervical and midthoracic spinal models with varying thicknesses of the dorsal csf-layer, corresponding to the ranges determined from the MRI scans. Two contacts with the dimensions of the Resume lead and a longitudinal separation of 6 mm were placed dorsomedially at the epidural border for bipolar stimulation. Threshold voltages for both a 15 μm DR-fiber and a 7.5 μm DC-fiber in the cervical model are shown in Fig. 2. Because DR-fiber thresholds are lowest for the whole range of csf-thicknesses, perception threshold is probably related to activation of this fiber type. Fig. 2 also shows that thresholds increase exponentially with csf-layer thickness (logarithmic Y-scale). One mm increase results in a threshold increase of the DR-fiber by a factor $\simeq$1.35 in the midcervical and the midthoracic model.

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