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Imaging Sensory Effects of Occipital Nerve Stimulation: A New Computer-based Method in Neuromodulation

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ABSTRACT

Background: Within the last years, occipital nerve stimulation (ONS) has proven to be an important method in the treatment of severe therapy-resistant neurological pain disorders. The correspondence between lead placement as well as possible stimulation parameters and the resulting stimulation effects remains unclear.
Objective: The method aims to directly relate the neuromodulatory mechanisms with the clinical treatment results, to achieve insight in the mode of action of neuromodulation, to identify the most effective stimulation sets and to optimize individual treatment effects.
Methods: We describe a new computer-based imaging method for mapping the spatial, cognitive and affective sensory effects of ONS. The procedure allows a quantitative and qualitative analysis of the relationship between lead positioning, the stimulation settings as well as the sensory and clinical stimulation effects.
Conclusion: A regular mapping of stimulation and sensory parameters allows a coordinated monitoring. The stimulation results can be reviewed and compared with regards to clinical effectiveness.

Introduction

Occipital nerve stimulation (ONS) as a special form of neuromodulation has proven to be an important method in the treatment of severe neurological pain disorders [1,2,9,10,12,15–18,20–25]. Important applications are in particular the treatment of therapy-resistant chronic migraine, cluster headache and other pain disorders not amenable to successful therapy. Methodologically, subcutaneous stimulation leads are implanted in the supply area of the greater, lesser, and third occipital nerves [18,23,25]. These are then electrically stimulated through an internalized neurostimulator. For therapy, different stimulation parameters are individually programmed [11,12,14,18,19,21,23,25]. The correspondence between lead placement as well as possible stimulation parameters and the resulting stimulation effects remains unclear. In particular, the relationship between the possible stimulation parameters such as stimulation frequency, pulse width, intensity and the resulting therapeutic effects is unknown. Furthermore, the influence of lead positioning onto the sensory and clinically-therapeutic stimulation effects remains unclear. In this study, we present a new method for analyzing these relationships. This new imaging method enables a mapping of the spatial, cognitive and affective effects of ONS. The imaging procedure aims to directly relate the neuromodulatory mechanisms with the clinical treatment results, to achieve an individual optimization of therapy.

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Materials and methods

For the graphical mapping of stimulation parameters a new computer-based application was developed. The program can be accessed through every standard web browser, as well as touch-screen devices. It can be used during the initial programming as well as later programming optimization stages of ONS. An internet-based application was chosen in order to allow mapping the stimulation and sensory parameters during the course of the treatment independently of location of the patients. Patients receive an individual username and password after activation by the treating physician. After logging in, the patient views the graphical user interface (Fig. 1). Navigation is possible using a mouse cursor or touch-screen. Via the implanted stimulation device, different programs can be activated for neuromodulation, which can be individually selected during a programming session. During the programming session, the mapping can be carried out with different given stimulation parameters, to qualitatively and quantitatively capture the effects of the chosen parameters. The patient first documents the program, for which he or she wishes to map the treatment effects. Using the patient's stimulation control device, the stimulation intensity for the respectively used program is selected and then documented using the graphical user interface. Thereafter, patients are able to map the sensory experiences and their intensity. This is done on a depiction of the back of the head, segregated into squares (Fig. 2). The image is standardized for all patients to avoid individual variability. The acquisition of the sensory effects can be carried out two-dimensionally by standardized squares. The standardization outweighs the disadvantage, that the exact individual three-dimensional localization is not depicted. The cutaneous distribution area of the occipital nerve was divided into four main quadrants on the right and left hand, which are further subdivided into a total of 18 sub-quadrants each. The localization of stimulation effects can be directly and objectively documented by identifying the relevant quadrants. At the same time, the perceived intensity can be quantitatively graded by a verbal category scale (0 = no sensation, 1 = very weak, 2 = weak, 3 = moderate, 4 = severe, 5 = very severe) using a color-coding system.

For the four main quadrants on the right and left side, the number of sub-quadrants can be automatically counted as a measure of quantifying the stimulation effects. The sum is determined directly for the corresponding main quadrant (Fig. 2). Further to that, a sum of the stimulation-induced perceived intensities is calculated and registered for each quadrant. In this way, both the spatial dimension of stimulation effects as well as the sum of stimulation-induced perceived intensities can be determined quantitatively and objectively. Additionally, the following scores are calculated: (A) number of squares on the right side of the head, (B) number of squares on the left side of the head, (C) sum of intensities on the right side of the head, (D) sum of intensities on the left side of the head. The program computes the products of $A \times C$ and $B \times D$. These scores are displayed in a chart (Fig. 2) and can be directly exported into a database for statistical analysis. The pleasantness/unpleasantness of perception can be scaled using the categories very pleasant, pleasant, neutral, unpleasant and very unpleasant. The quality of perception can be categorized qualitatively using the characteristics tingling, vibrating, pinching, knocking and pulsating. The general clinical effectiveness in the therapeutic setting can be documented using the categories very good, good, moderate, poor and very poor. Additionally, free comments can be entered for the relevant mapping by the patient. The data are saved under the date and the number of the program to the central database. The administrator receives an email with this information, can review the stimulation results and initiate a change of the stimulation parameters in the course of the treatment.

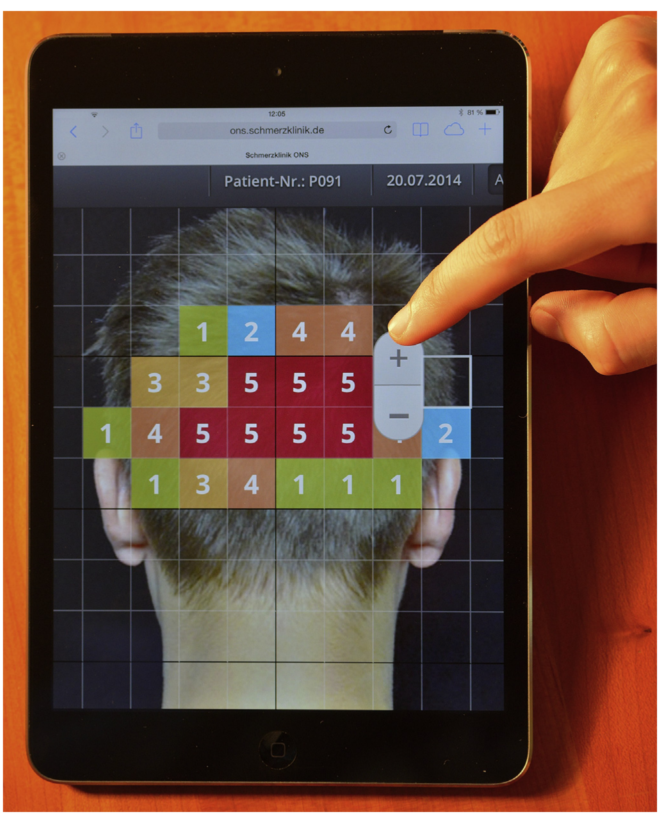

Figure 1. Mapping of spatial distribution and intensity of induced sensory experiences by occipital nerve stimulation using a touch-screen device. By clicking the squares of the grid, the intensity of sensation can be entered, by clicking more than once, the intensity score increases The scaling of intensity by a verbal category scale is as follows: 0 = no sensation, 1 = very weak, 2 = weak, 3 = moderate, 4 = severe, 5 = very severe.

Implementation

The leads are typically positioned subcutaneously in the left and right innervation area of the occipital nerve. On each side, an octopolar lead is implanted and connected to a neurostimulation device. The stimulation electrodes can be individually programmed with regards to polarity, amplitude, frequency, pulse width and current direction. Figure 2 shows a stimulation field for an individual program selected for clinical use. A wide dissemination of induced paresthesia areas can be seen. The intensity of paresthesia is strong (Numerical analog scale 0 = no sensory effect to 5 = very severe sensory effect). They are described as very pleasant and tingling. The patient describes the clinical effectiveness as good. Differing stimulation intensities change the spatial distribution and the intensity of the induced sensory experiences. A higher stimulation amplitude can enlarge the stimulation area, but also change the sensory quality and pleasantness simultaneously. The relationship can be mapped directly. This is equally true for the frequency and pulse width. Both can enlarge the stimulation field size, the intensity of paresthesia, as well as their pleasantness and somatosensory quality.

Discussion

Occipital nerve stimulation and other neuromodulatory approaches have become new established op tions in the therapy of severe and therapy-resistant chronic headache [1,2,9,10,12,15,16,18,20–25]. Despite great advances in the technical improvement of