Integration of NBS functional mapping data via StealthStation® into neuronavigated OPMI® Pentero® surgical microscope

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Background

In recent years, the neurosurgical operating microscope has undergone rapid development, increasingly becoming the neurosurgeon’s workstation for open microneurosurgery. Integration of the surgical planning data, image-guided orientation, and automatic laser-guided optical focusing are significant developments which support more precise delineation between the normal and pathological brain tissue. Brain tumours as well as vascular malformations may significantly alter the normal functional neuroanatomy which makes the delineation of safe resection by anatomical landmarks challenging, especially when the lesions lie close to the eloquent cortical or white matter areas. The integration of accurate and reliable functional localization data into the neurosurgeon’s visual field would allow safer and more complete resections.

Navigated Brain Stimulation (NBS) is a non-invasive transcranial magnetic stimulation (TMS) technique for the accurate localization of cortical muscle representation areas displayed in detailed cortical anatomy of individual MR images. The functional cortical mapping data obtained by the NBS System (Nexstim Oy, Helsinki, Finland) can be transferred to the neuronavigation system for display during surgery (Figure 1).

Figure 1: The NBS System (left) used preoperatively to map the motor cortical areas. The NBS functional data and the anatomical MR images are exported (DICOM) to the Medtronic StealthStation® neuronavigation system (centre) for fusion and outlining of the tumour and critical motor cortex volume. Anatomically and functionally guided open microsurgery is performed under the neuronavigated OPMI® Pentero® surgical microscope (right). Direct electric cortical and white matter stimulation (DCS) with EMG monitoring of the contralateral muscles of the face, upper arm and lower arm is performed under general anaesthesia without neuromuscular blockade.

The OPMI® Pentero® (Carl Zeiss Surgical GmbH, Oberkochen, Germany) is a new generation surgical microscope optimized for neurosurgery. It offers the neurosurgeon a “virtual cockpit”-view of the surgical field, integrating the navigation and planning information generated in the pre-surgical planning stage with real-time visual surgical field. The sophisticated cockpit view avoids the distraction caused by looking for information from separate monitors - a safety concern because the direct visual contact with the surgical field and instruments used is temporarily interrupted.

In the present study, we examined (a) whether the preoperative NBS mapping data of the primary motor cortex (M1) can be projected into the surgeon’s visual field through the neuronavigated microscope, and (b) whether the mapping data so projected over the cortex is valid when correlated to the direct electric cortical stimulation mapping of M1.

Navigated Brain Stimulation (NBS)

NBS is a noninvasive technique mimicking the stimulation of direct electrocortical stimulation (DCS). Instead of generating an electric field through stimulating electrodes placed on the exposed cortex and white matter, with NBS an intracranial electric field (E-field) is induced by triggering a transcranial magnetic stimulation (TMS) coil placed externally over the head. The simultaneous measurement of peripheral motor evoked potentials (MEP) by electromyography (EMG) is used to identify and verify the motor representation areas in the cortex, in the same manner as in DCS. Excellent resolution of the motor representation areas is achieved by using a purpose-built figure-of-eight coil, and adjusting the E-field strength to the individual patient’s motor threshold (MT). As compared to DCS, NBS mapping is noninvasive and can be performed preoperatively as an aid to the patient selection and preoperative planning for surgery or the implantation of, e.g., intracranial EEG electrodes (Säisänen L, et al. 2010; Epilepsy surgery candidates).

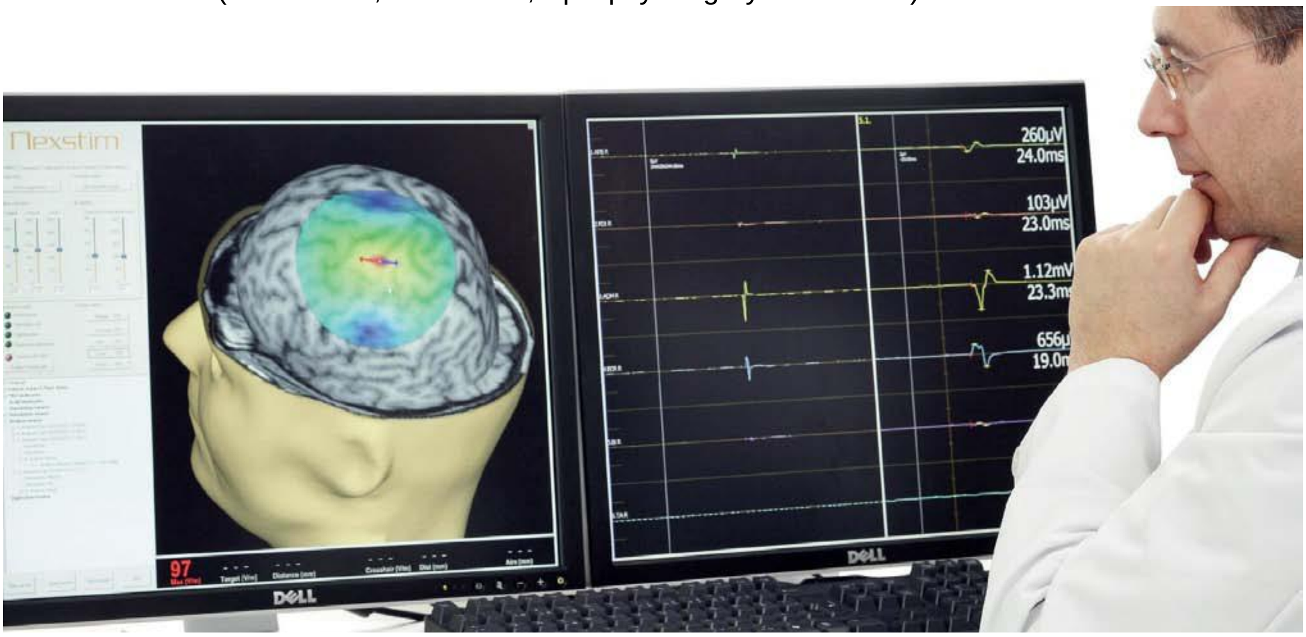

Figure 2: NBS System user interface and stimulation planning screen (left). Location of the E-field maximum is visualized in a 3D rendering of the brain. The 6-channel EMG motor response screen (right) displays online EMG in the right window and triggered EMG responses in the left window.

Preoperative NBS mapping is fully compatible with the intraoperative neuronavigation because the same MRI dataset is used as the basis of NBS mapping as well as for the navigation of the OPMI® Pentero® surgical microscope by the StealthStation® neuronavigation system (Medtronic Inc., Minneapolis, MN, USA). In NBS mapping, the MRI dataset is used to link the location of the TMS-generated E-field to the individual patient's cortical anatomy. Using familiar stereotactic navigation techniques, movement of the TMS coil guides the predicted E-field location through the intracranial structures. DICOM-export of motor response maps from the NBS System permits direct integration of functional mapping data into the DICOM-compatible OPMI® Pentero® surgical microscope, allowing NBS mapping information to be viewed on the tissues exposed.

Patient case

A 75-year-old male exhibited a brain tumour in the right hemisphere close to the M1. An axial 3D T1 MRI dataset with 1x1x1mm voxels was obtained. After loading the MRI dataset to the NBS System, the patient was prepared for the cortical mapping session. As a standard precaution in our hospital, scalp EEG electrodes were used to monitor possible epileptic seizures. EMG surface electrodes were placed over the muscles corresponding to the critical motor areas in the cortex. The NBS mapping was initiated by localizing the cortical representation area of the thenar muscle and determining its MT in the healthy hemisphere. MT was then determined for the lesioned side. Mapping of the motor cortical areas was performed with the stimulation intensity adjusted for the lesioned side to 110%, 105%, and 100% of thenar muscle MT.

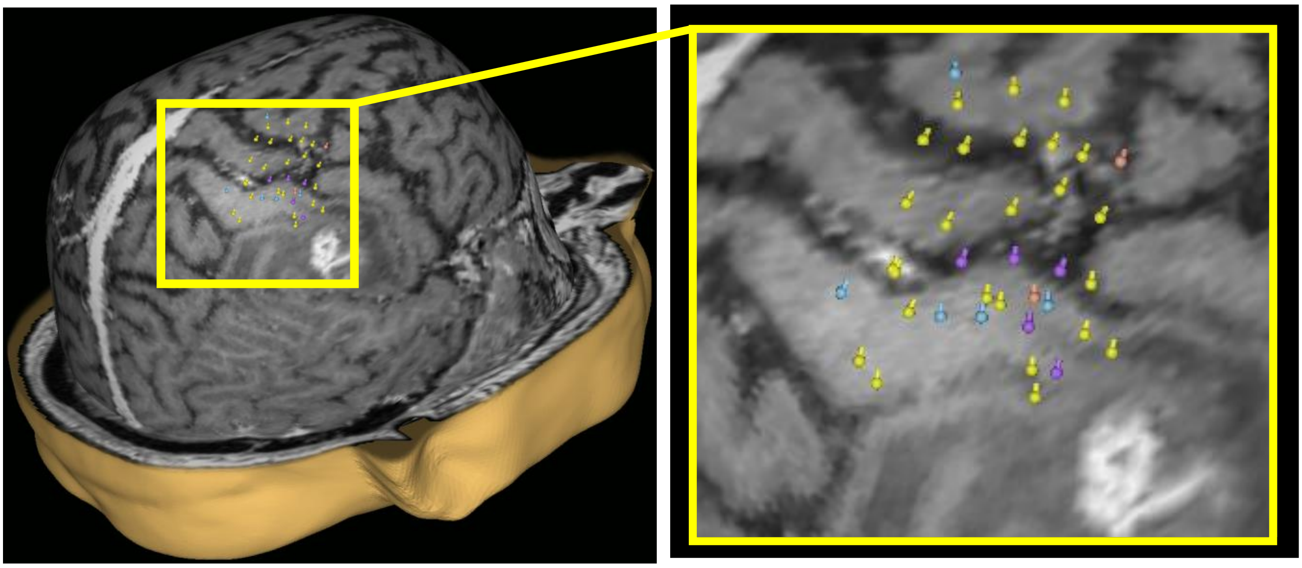

Figure 3: The NBS System screen display of stimulating E-field locations on the right hemisphere, recorded during the mapping session at 110% of MT, (detailed view on right). NBS System software calculates the maximum E-field locations within the cortex and colour-codes them according to their corresponding muscle with the highest MEP: m. opponens pollicis (pink), m. abductor digiti minimi (yellow), m. flexor carpi radialis (blue), and m. extensor digitorum communis (purple).

The data file of the mapping session was retrieved from the NBS System via an NBS planning station for post-processing. The maximum E-field locations corresponding to the stimulated locations eliciting responses in muscles were selected for creating the DICOM image. The anatomical MRI dataset and the NBS results were uploaded to a StealthStation® neuronavigation system, and fused. Using the StealthStation® neuronavigation system, the tumour margin ROI and the NBS localized motor area were drawn as objects and stored in the system's database. In the OR, the patient was co-registered with the MRI dataset in the StealthStation® neuronavigation system. After connecting the StealthStation® neuronavigation system to the OPMI® Pentero® surgical microscope the objects drawn in the planning stage could now be projected in the visual surgical field of the microscope and superimposed on the brain tissue exposed for surgery.

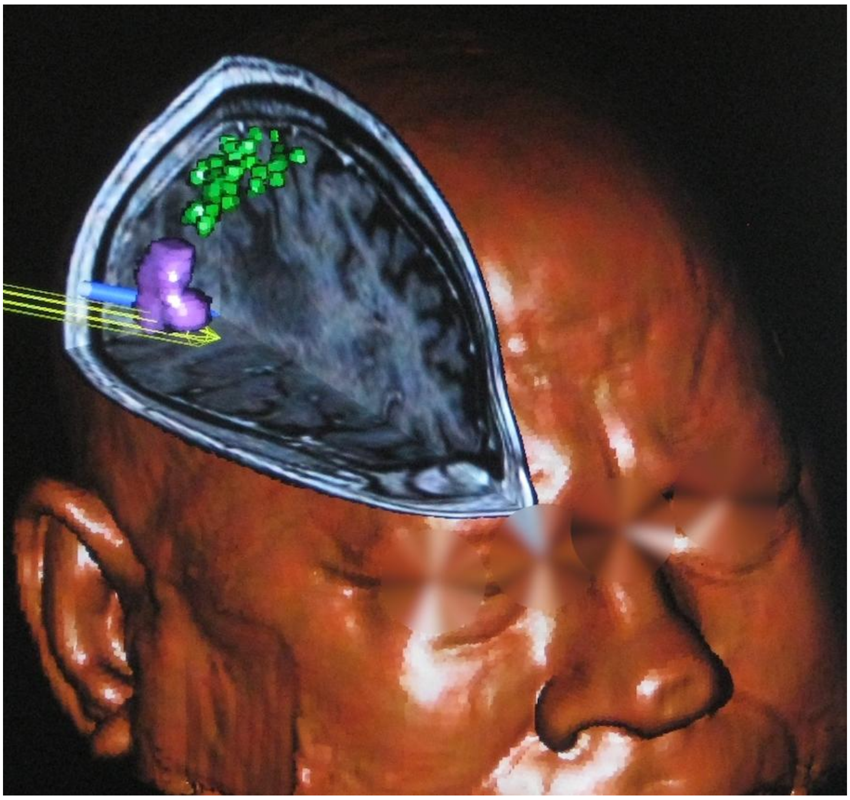

Figure 4: The NBS mapping data fused into the 3D MRI data set of the patient's head as displayed on the StealthStation® neuronavigation system screen. The tumour volume is delineated with purple.

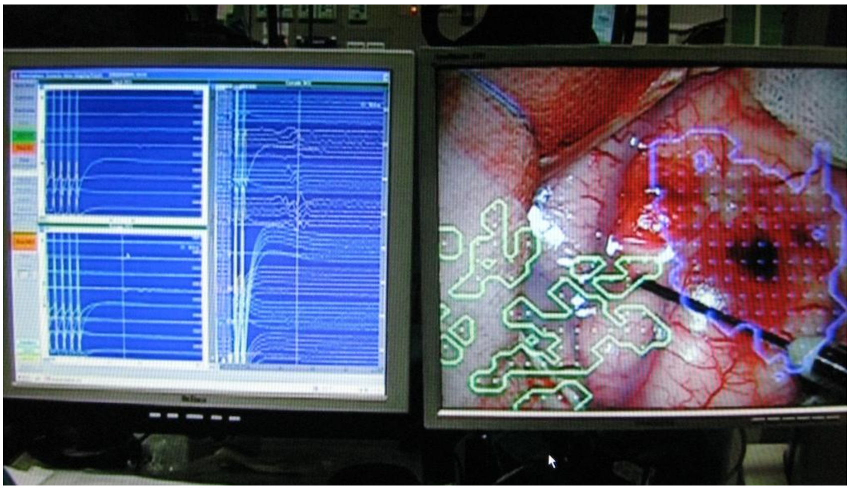

Figure 5: Surgical visual field through the neuronavigated OPMI® Pentero® surgical microscope on a remote monitor (right). The NBS mapped primary motor area of the hand is visualized with green borders. The tumour region in the MR images, used as the anatomical basis for the preoperative NBS study as well as in the StealthStation® neuronavigation system, is delineated with a purple border. The remote monitor (left) displays real-time EMG responses from DCS of the contralateral muscles of the face, upper arm and lower arm.

Figure 6: Neurosurgical OR at Kuopio University Hospital, equipped with an OPMI® Pentero® surgical microscope and a StealthStation® neuronavigation system. The OPMI® Pentero® remote monitor displays the surgical visual field together with NBS-mapping results, projected through the microscope from the StealthStation® neuronavigation system as a DICOM image.

Results

In this patient case study, NBS data and the DCS data of the M1 were found to be well overlapping. Brain shift was minimal as the DCS mapping was performed immediately after the dura was opened.

This study illustrated that the integration of preoperative functional localizing data of eloquent motor areas into the OPMI® Pentero® surgical microscopes was straightforward and very practical. The data projected into the visual surgical field supported safer and optimal resection of a lesion in a critical functional location. DICOM compatibility enabled the mapping data from the Nexstim NBS System to be introduced via a StealthStation® neuronavigation system into the operation room workflow reliably, with minimal additional time and workload required from the supporting personnel.

Conclusion

Integration of functional mapping data from the Nexstim NBS System via the Medtronic StealthStation® neuronavigation system into the surgical visual field of the neuronavigated Zeiss OPMI® Pentero® surgical microscope is a clinically practical concept and supports safer and optimal resection of lesions near critical functional locations.