White matter tractography based on Navigated Brain Stimulation results in Brainlab iPlan

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Background

The integration of anatomical and functional studies allows safer resection of brain tumours located in close proximity to eloquent areas. A multimodal software solution (iPlan Cranial software, Brainlab AG, Feldkirchen, Germany) allows integration and correlation among preoperative and intraoperative anatomical and functional data for comprehensive planning of neurosurgical procedures. The clinical value of the planning software is dependent on the accuracy and reliability of the patient data entered.

Diffusion tensor (DT) imaging and white matter fibre tractography are accepted MR-imaging techniques utilizing the concept of anisotropic water diffusion in myelinated fibres. Tractography enables 3D reconstruction and visualization of white matter tracts and provides information about the relationship of these tracts to the eloquent areas and the lesion. An important challenge for reconstructing white matter fibres is the definition of a functionally meaningful seed area for starting the tracking process. In patients with brain tumours, the functional neuroanatomy of the patient may be significantly affected by the lesion which makes it difficult to define seed areas based solely on anatomical landmarks.

The NBS System (Nexstim Oy, Finland) is a novel method for accurate, noninvasive mapping of the motor cortex which has recently become available for presurgical use. In this study we examined the clinical value of integrating Navigated Brain Stimulation (NBS) functional mapping data directly into the iPlan software solution as an aid to selecting originating seed areas for white matter tractography.

Figure 1: Nexstim NBS System (left) → DICOM export → Brainlab iPlan station (center) and navigation system (right).

Navigated Brain Stimulation

NBS is a noninvasive technique for electrocortical stimulation. Instead of generating an electric field from electrodes placed on the exposed cortex, as in intraoperative direct electrocortical stimulation (DCS), with NBS the electric field (E-field) is induced intracranially by triggering a transcranial magnetic stimulation (TMS) coil placed externally to the head. The simultaneous measurement of 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 with DCS. Excellent resolution of the motor representation areas is achieved by using a purpose-built figure-of-8-coil and adjusting the field strength to the individual patient's motor threshold.

Compared to DCS, NBS mapping has the advantage that it is noninvasive and can therefore be used preoperatively as an aid in surgical planning and reviewing patient selection for surgery or other therapeutic options.

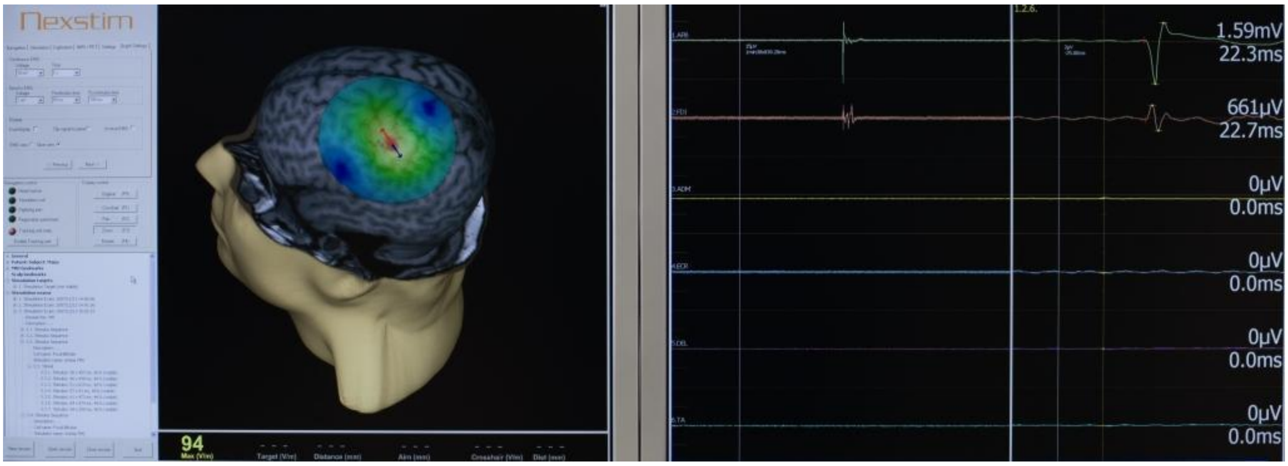

Figure 2: Nexstim NBS System user interface and stimulation planning screen (on left), 6-channel EMG motor response screen (on right).

Mapping with NBS is fully compatible with the surgical navigation paradigm since the same MRI dataset is used as the basis of both presurgical planning and intraoperative guidance. In NBS mapping the MRI dataset is needed to link the location of the TMS-generated E-field to the individual patient's cortical anatomy. Using familiar stereotactic navigation techniques, moving the TMS coil guides the E-field location through the intracranial structures. The 3D rendering of the MRI dataset by the NBS System is a helpful feature for orientation and location of the cortical somatotopy with respect to the intracranial anatomical structures.

DICOM-export of motor response maps from the NBS System permits integration of NBS mapping data with other modalities within iPlan software.

Methods

Functional mapping of the motor cortex was performed with the NBS System. 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 were selected and verified before the motor mapping image - generated from the corresponding MEP responses - was exported in DICOM format to a portable memory device.

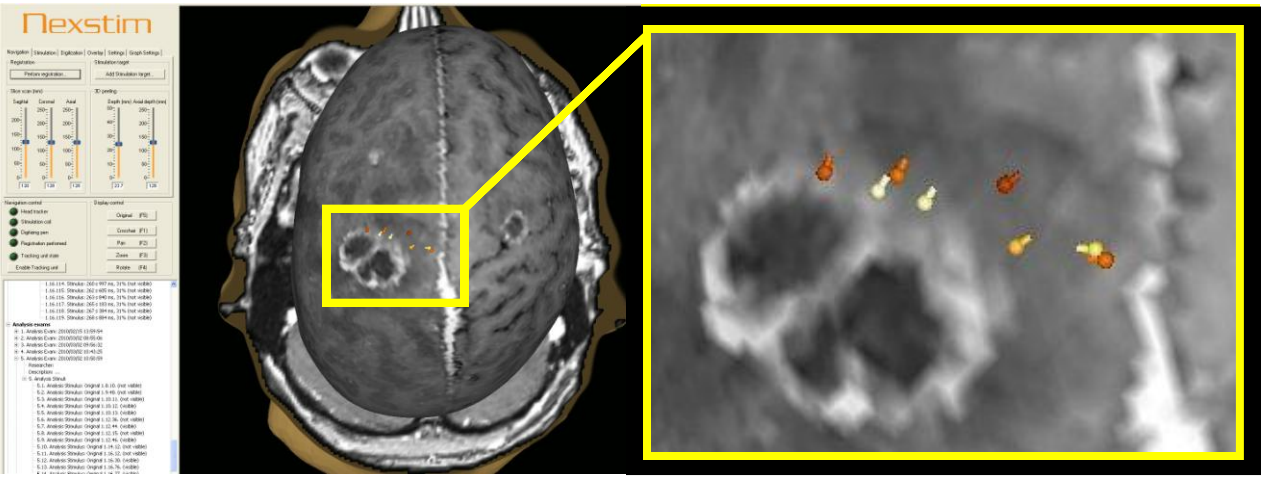

Figure 3: Stimulating E-field locations recorded in the mapping session as displayed on NBS System (left). NBS software calculates the maximum E-field locations within the cortex and colour-codes them according to their corresponding peak-to-peak MEP amplitudes, making a heat map. Locations eliciting the largest MEPs are colour-coded white in the heat map (enlarged image, right).

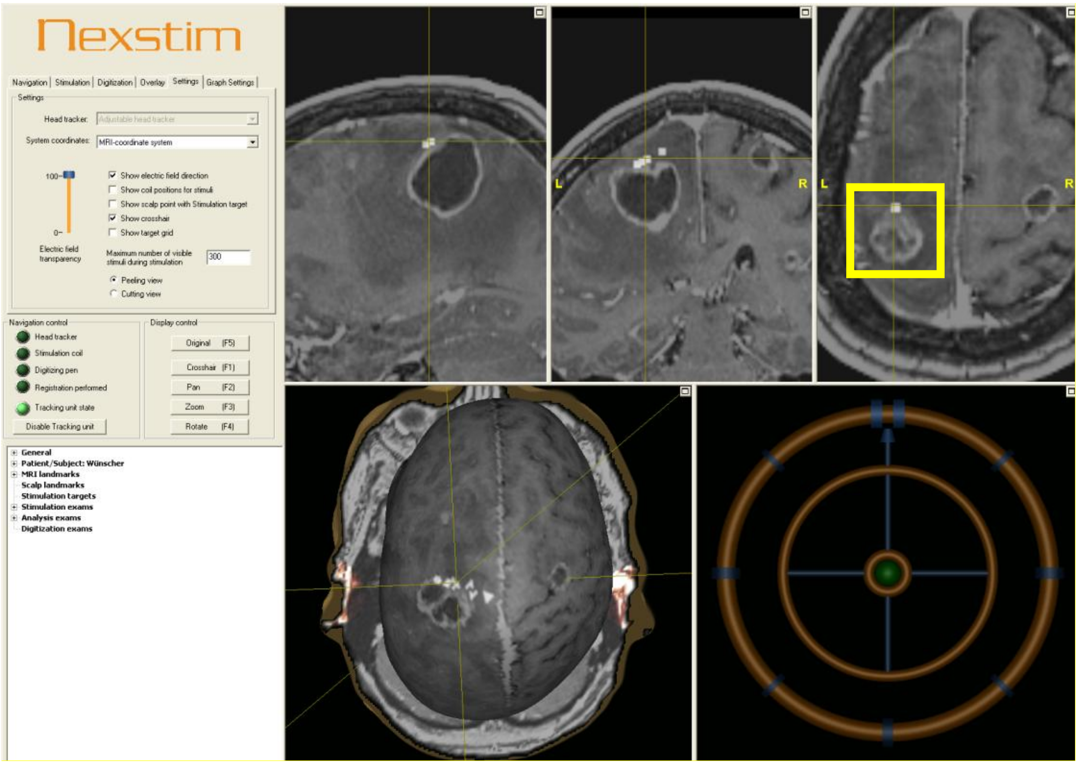

Figure 4: DICOM-export of stimulation locations visualized on the Nexstim NBS screen. The MEP maximum response for the largest hand muscle, abductor pollicis brevis (APB), is defined as the "hot spot" to be used in the Brainlab iPlan software as the seed region for tractography of the pyramidal tract. The APB hotspot is in the immediate vicinity of the tumor (highlighted in the top right image in the figure).

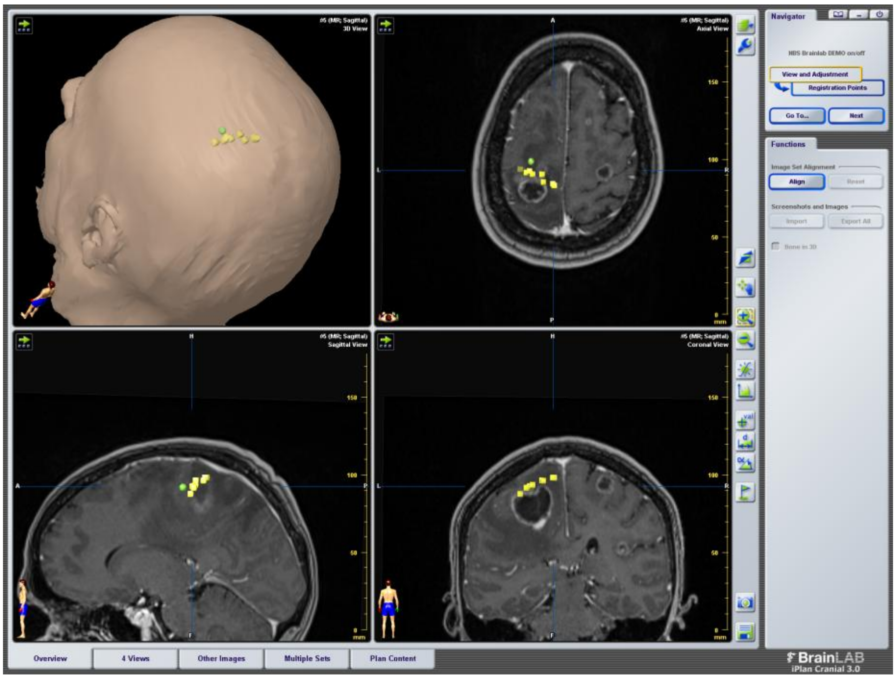

Figure 5: The patient's MRI dataset, NBS mapping image and DT-imaging data were uploaded to iPlan. Following image fusion, MEP maps from the NBS motor mapping session are displayed in the 3D navigational image and can be used as seed regions for applying the tractography algorithms to visualize the white matter tracts from the primary motor cortex. The location of the largest MEP response for the APB muscle used for the seed regions is colour-coded green in iPlan.

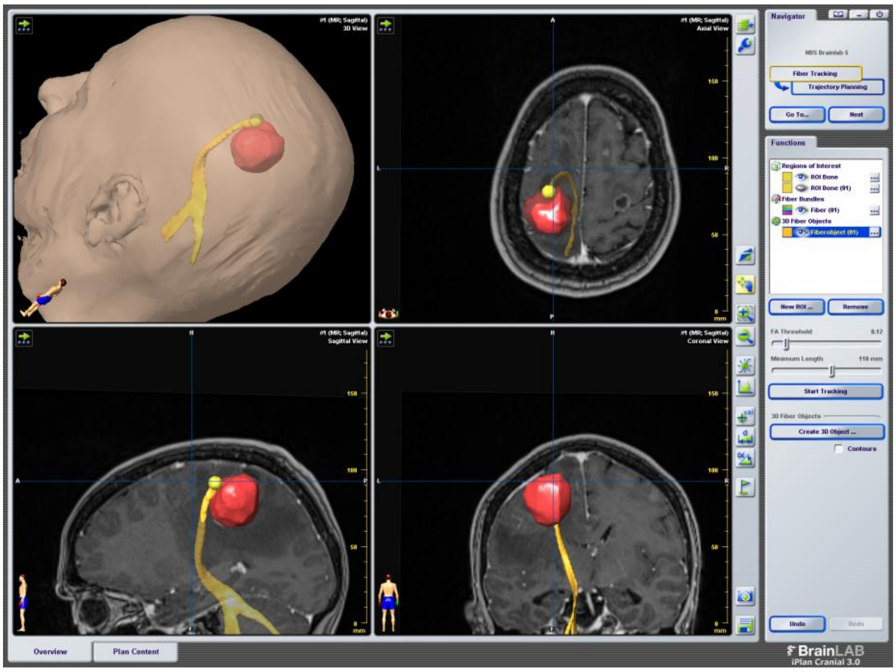

Figure 6: Visualization of fibres originating from the APB hot spot after converting the tractography results - without any postprocessing - into a 3D object for export to a Brainlab navigation system. Tumour marked in red, APB hotspot visualized as yellow sphere.

Results and Conclusion

Functionally meaningful seed areas were reliably determined from the non-invasive NBS motor mapping data and permitted a more specific white matter fibre construction process.

The study illustrated that accurate and reliable noninvasive motor mapping data can greatly facilitate tractography. Using DICOM export of NBS motor mapping data to the iPlan system to select seed areas could potentially remove a key obstacle to the wider clinical application of DT-imaging and tractography.

NBS-guided fibre tractography is a promising new multimodal technique for preoperatively generating functionally-relevant white matter networks and validating the reconstructed fibres. NBS has the potential to add significant new functionality to the Brainlab iPlan system for planning surgical trajectories that can help preserve critical subcortical motor pathways, as well as cortical motor areas, during tumour resection.