Integration of Navigated Brain Stimulation (NBS) functional mapping data into GammaPlan® stereotactic radiosurgery planning software for treatment of brain tumors

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Background

Stereotactic radiosurgery (SRS) is an established method for treating focal intracranial tumors with good results. However, SRS close to eloquent cortex carries the risk of new neurological deficits. Incidences of new motor deficits of up to 26% have been reported for radiosurgery of metastatic brain tumors in the motor cortex (1). To prevent complications, planning of radiosurgery is performed with the aim of minimizing the exposure of functionally critical cortex to radiation. In practice, this is done based on approximate neuroanatomic locations of cortical functions. However, this does not allow for patient-specific variation or fully reflect the functional anatomy of the individual patient.

Navigated Brain Stimulation (NBS) is a non-invasive transcranial magnetic stimulation (TMS) technique. In NBS mapping, the patient's MRI dataset is used to link the location of the TMS-generated stimulating electric field to the individual patient's cortical anatomy. Using familiar stereotactic navigation techniques, movement of the TMS coil guides the calculated 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 other DICOM-compatible software applications, allowing NBS results to be viewed during intervention planning. In clinical studies in brain tumor surgery, the system localized the motor cortex in all patients to the same gyrus as intraoperative direct cortical stimulation (DCS). According to the operating neurosurgeons, the results of preoperative mapping of the motor cortex with NBS are as accurate as DCS (2, 3).

Gamma Knife® (Elekta AB, Stockholm, Sweden) is a widely used, well-established platform for performing accurate stereotactic radiosurgery (SRS). The device and the therapy planning software, GammaPlan®, facilitate the delivery of a single dose of radiation to the intra-cranial target through the intact skull.

Integration of the patient specific NBS results into SRS planning software may provide an additional tool to decrease the likelihood of complications affecting the motor system. We therefore examined whether the pre-procedural NBS mapping results of the localization of the primary motor cortex (M1) can be integrated into the GammaPlan® software and used for planning SRS delivery.

Figure 1: NBS workstation incorporating TMS stimulator, stimulating coil, EMG and navigation software in a single clinical system. In the user interface the location of the stimulation target and locations providing responses are visualized in a 3D rendering of the brain on the stimulation planning screen (left screen). The 6-channel EMG motor response screen (right screen) displays online EMG and triggered EMG responses in real time.

Patient case

A 62-year-old female exhibited a metastasis secondary to breast cancer in the left hemisphere close to the M1. A stereotactic 3D T1 MRI dataset with 1.5x1.5x1.5mm voxels was obtained. After loading the MRI dataset to the NBS System, the patient was prepared for the cortical mapping session. 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 motor threshold (MT). Mapping of the hand motor cortical areas was performed with the stimulation intensity adjusted for the lesioned side to 110%, of thenar muscle MT. Mapping of cortical representation for leg muscles (m.tibialis anterior (m.TA) and m.abductor hallucis brevis (m.AH)) was then performed utilizing a stimulator intensity generating an electric field 20V/m higher than that used for hand muscle mapping.

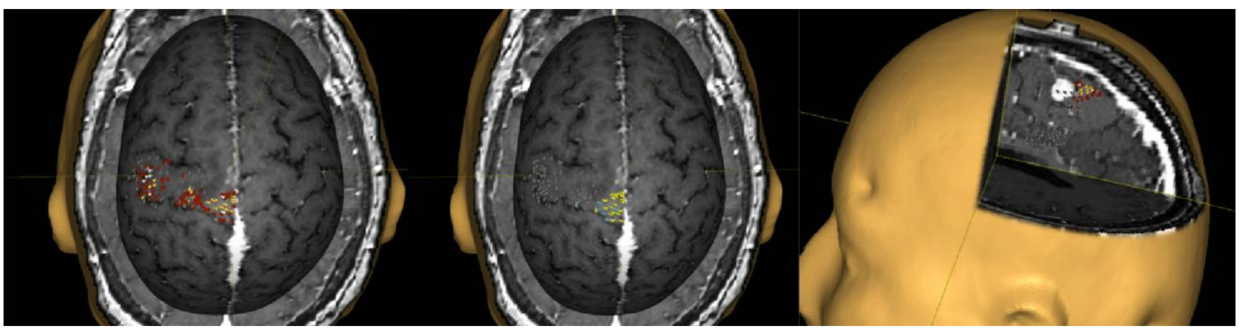

Figure 2: Results of the NBS motor mapping. Left panel: Locations of motor evoked potentials of hand and leg muscles (thenar, biceps, and leg) elicited from the M1 cortex with NBS color coded according to size of response (white>yellow>red). Middle panel: Locations of motor responses from the leg muscles (yellow=responses from m.TA, blue=responses from m.AH). These leg muscle responses were exported to the GammaPlan® software for treatment planning. Right panel: the leg muscle motor responses from middle panel visualized in the 3D head model generated by the NBS software in relation to the tumor location. The responses are color coded according to size (white>yellow>red. Grey= no response to stimulation). The tumor metastasis to be treated with Gamma Knife® is visible as the contrast-enhanced structure just to the front of the NBS responses, in the left hemisphere, close to midline.

The data file of the mapping session was retrieved from the NBS System for post-processing.
The maximum electric 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 GammaPlan® software and co-registered. The NBS results could then be viewed in the GammaPlan® software and used for planning the SRS.

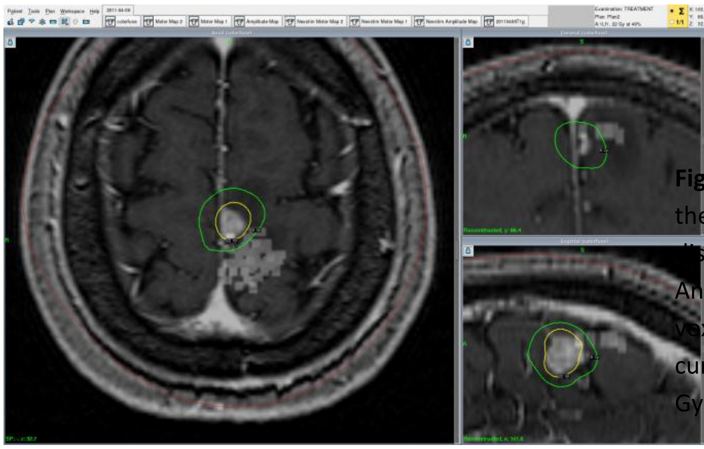

Figure 3: The NBS mapping data co-registered with the anatomic MRI data set of the patient's head as displayed on the GammaPlan® system screen. Anatomic MRI with NBS results visible as grayscale voxels. The treatment plan visualized as isodose curves around the tumor (coloured lines, yellow= 22 Gy, green=9 Gy).

Visualization of the NBS data in the GammaPlan® software indicated that the primary motor cortex was located in the gyrus bordering the metastasis with the leg motor representation areas adjacent to the tumor. Based on the data the treatment plan was modified to avoid extensive exposure of the motor areas to radiation while ensuring sufficient irradiation of the metastasis as depicted in Figure 3.

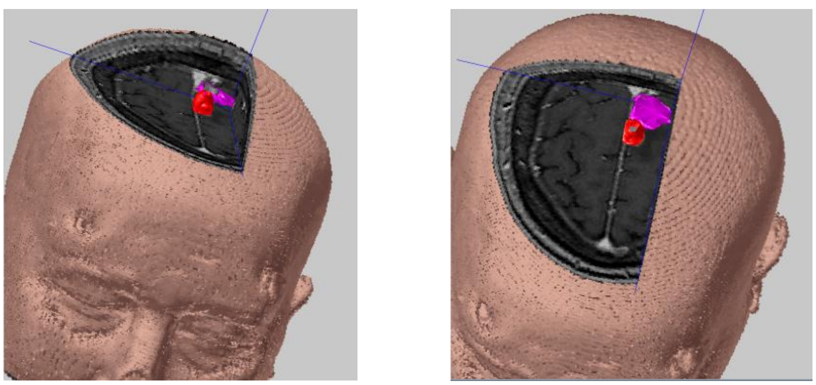

Figure 4: A 3D cut view of the patient's head visualizing the relative positions of the tumor metastasis (purple) and the closely adjacent leg motor areas determined with NBS (magenta) in the GammaPlan® software. Left panel: view from front right. Right panel: view from top.

Conclusion

The study demonstrates that accurate patient-specific NBS motor mapping data can be successfully integrated into GammaPlan® software, provides information useful for clinical decision-making and can be used for planning optimal SRS delivery.

References

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