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Visualization of small veins with Susceptibility-Weighted Imaging for stereotactic trajectory planning in Deep Brain Stimulation

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ABSTRACT

Intracerebral hemorrhage (ICH) is the most significant complication of Deep Brain Stimulation (DBS). To prevent ICH, stereotactic contrast enhanced T1-weighted images are used to visualize vessels as source of hemorrhage. Susceptibility-Weighted Imaging (SWI) is an MRI sequence with improved visualization of susceptibility differences between tissues, particularly sensitive for brain veins. The aim of this prospective study was to analyze the utility of SWI compared to contrast enhanced stereotactic T1-weighted images for trajectory planning of DBS. Preoperative SWI was performed in 33 patients undergoing DBS and was compared to the T1-weighted images. Vessels identified only with SWI in relation to the bilateral planned trajectory were analyzed. In all patients vessels were depicted on SWI only within the planned trajectory (range 1–4 vessels, for each trajectory, mean: 2.4). In 6 patients vessels were identified on SWI adjacent to the target (up to 5 mm distal from target). In 11 patients SWI visualized additional cortical veins adjacent to the entry point of the trajectory. The apparent diameter of these vessels ranged between 0.8 and 2.1 mm (mean: 1.2 mm). Postoperative MRI was compared with preoperative SWI and revealed in two patients small (<3 mm) T2 hyperintense lesions along electrodes without correlation with visualized veins. SWI facilitates the visualization of small veins superior to T1-weighted images. However, cerebral veins within the trajectory were not found to be a significant source of ICH after DBS. Potential sources of ICH are mesencephal veins at the endpoint of electrodes which can cause fatal hemorrhage and are visualized with SWI reliably.

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1. Introduction

Deep Brain Stimulation (DBS) is an effective treatment for various movement disorders such as Parkinson's disease, segmented and general dystonia, and essential tremor [1–3]. Stereotactic magnetic resonance imaging (MRI) based placement of the electrodes has been performed for different targets: subthalamic nuclei (STN), globus pallidus internus (GPI) and ventralis intermedius of thalamus (VIM). The success of the DBS depends on the precise image guided planning of the target and trajectory. Individualized planning is possible using atlas based coordinates and MRI based direct visualization of the target [4–9]. Stereotactic MRI based software is used to plan an optimal trajectory from the defined entry point to the stimulation target by avoiding critical brain structures. Symptomatic intracerebral hemorrhage (ICH) is the most significant complication of DBS with an incidence between 0.9 and 5% [10,11]. ICH is a limitation of the benefit of DBS for the patients and can cause a fatal outcome if located in the brainstem. Stereotactic gadolinium enhanced T1-weighted images are used routinely at our department to visualize the vessels for planning the trajectory and to avoid injury of these vessels within the trajectory. In most cases, a correlation of ICH to the visualized vessels cannot be found. The cause of the hemorrhage is still unknown. Cerebral venous infarction has been described as a rare complication of DBS [12], but there are no studies on veins as a potential source of hemorrhage. With contrast enhancing T1-weighted images mainly arterial vessels can be visualized. Susceptibility-Weighted Imaging

Abbreviations: ICH, Intracerebral hemorrhage; SWI, Susceptibility Weighted Imaging; DBS, Deep Brain Stimulation; STN, subthalamic nuclei; GPI, globus pallidus internus; VIM, ventralis intermedius of thalamus.

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like T2* weighted angiography (SWAN, General Electric), Susceptibility weighted imaging (SWI, Siemens) and venous blood oxygen level dependent (VenoBOLD, Philips) are relatively new contrast MRI sequences for improved visualization of susceptibility differences between tissues [13–16]. With these MRI sequences small brain veins can be visualized reliably with a diameter less than one millimeter [17]. We hypothesized that for the trajectory planning of electrodes for DBS, otherwise invisible vessels as source of hemorrhage could be visualized within the trajectory. The aim of this prospective study was to compare SWI and stereotactic contrast enhanced T1-weighted images to determine the value and utility of SWI for trajectory planning of stereotactic electrode placement in DBS.

2. Methods

From all patients undergoing DBS ($n = 610$) at our department, 33 consecutive patients (19 male, 14 female, age ranged between 13 and 82 years, mean age 58 years) were included in this prospective study. The study was approved by the ethical review board of the university. The participation of patients in this study was performed with the consent of each patient. All patients had undergone neurological evaluation and MRI preoperatively to verify the indication for DBS. All patients were candidates for DBS without any contraindication. The indications for DBS were Parkinson's disease in 26, essential tremor in four and general dystonia in three patients. The target for DBS in the study group was STN in all patients with Parkinson's disease, VIM in tremor patients and GPI in patients with dystonia.

On the day of the operation all patients underwent general anesthesia. Thereafter the stereotactic ring with the localizer was placed on the patient's head with four screws and MRI scan was performed in the intraoperative MRI unit. This procedure ensures high quality images without head movement. The patients with Parkinson's disease and essential tremor were waked up after MRI scan in the recovery room after performing local anesthesia on patient's head. The microelectrode recording and the test stimulation in this group were performed in awake patients. In patients with general dystonia surgery was performed under anesthesia with reduced sedation due to uncontrolled movement of these patients.

Susceptibility-Weighted Imaging (VenoBOLD) and stereotactic contrast enhanced T1-weighted images were acquired (1.5 Tesla, Philips Medical Systems, Best, Netherlands) in all 33 patients. In addition T2-weighted or Inversion Recovery MR-images were performed depending on the planned target [9,18,19]. Due to recommendation of the ethical review board, SWI was not used for the planning of the trajectory to avoid unintended influence to standardized DBS procedure. Contrast enhanced stereotactic T1-weighted MRI was used for trajectory planning in all patients. The standardized planning was performed by definition of the target and looking for the optimal entry point by avoiding visualized vessels within the trajectory. The trajectory was planned with a diameter of 4.5 mm allowing neurophysiological microelectrode recording and intraoperative stimulation with up to five electrodes. The intraoperative microelectrode recording was started 4 mm proximal up to 3 mm distal of the planned target point. After each millimeter microelectrode recording was performed. The results of the microelectrode recording were used for electrophysiological localization of the target. Thereafter, the stimulation was performed in millimeter steps up to 3 mm distal of the target looking for the best stimulation result and lowest undesirable side effects of stimulation. The final electrode placement depends on intraoperative microelectrode recording and stimulation results and was done 2–3 mm below the target point with best stimulation result to ensure optimal position of the electrode contacts.

Without modification of the intended trajectory, SWI was analyzed after surgery and compared to contrast enhanced stereotactic T1-weighted MRI. SWI was coregistered with the stereotactic gadolinium enhanced T1-weighted images (Fig. 1A) using the automatic image fusion of the planning software (Brainlab, Heimstetten, Germany). The coregistered images were compared and used for the evaluation of the vessels. A total number of 66 trajectories in 33 patients were analyzed. The vessels which were identified only with SWI within the planned trajectory corridor (Fig. 2) were counted and the diameters were measured. The images were analyzed additionally for visualized veins within a radius of 5 mm from planned target and entry point. In cases with visualized veins located distal from the planned target point in extension of the planned trajectory (up to 5 mm), an alternative trajectory planning was simulated in the manner to avoid the veins on SWI.

Postoperative MRI was performed in all patients and was coregistered with preoperative stereotactic MRI to control electrode placement in relation to the planned trajectory and to verify postoperative complications.

3. Results

In all 33 patients, 66 trajectories were planned with stereotactic T1-weighted MRI with gadolinium for microelectrode recording, test stimulation and electrode placement for bilateral Deep Brain Stimulation. Intraoperative neurophysiological microelectrode recording and stimulation with up to five electrodes for each trajectory were performed. Electrophysiological localization of the target succeeded and according to the microelectrode recording and stimulation results, an optimal target point could be determined in all patients. The patients underwent stereotactic bilateral electrode placement.

Additional time required for acquisition of SWI was 6–8 min without technical problems. Coregistration of SWI with stereotactic T1-weighted MRI with gadolinium was possible in all cases. For each patient, SWI could visualize additional vessels inside the trajectory which were not visible on stereotactic T1-weighted images. For each trajectory a mean number of 2.4 vessels were identified additionally with SWI (range 1–4 vessels) within the final trajectory. Within a radius of 5 mm from planned target and entry point, SWI depicted not otherwise visible small veins (range 1–5 vessels). In 6 patients the visualized veins were distal from to the planned target in extension of the trajectory. A reliable alternative trajectory could be planned in all 6 cases avoiding the visualized veins within the virtually extended trajectory. In 11 patients SWI visualized additional cortical veins with a distance to the entry point ranged between 1 and 5 mm. The apparent diameter of the additionally visualized vessels on SWI ranged between 0.8 and 2.1 mm (mean: 1.2 mm).

Postoperative MRI showed correct electrode position in all cases and detected small (<3 mm) asymptomatic T2 hyperintensive lesions in two patients along the implanted electrode. These asymptomatic lesions were located in frontal white matter and were not considered as ICH. Analysis of the coregistered postoperative MRI of these two patients revealed that the visualized veins along the trajectory did not correlate with the T2 hypertensive lesions.

4. Discussion

Deep brain stimulation (DBS) is an effective and generally safe treatment for various movement disorders with high benefit for the patients and low complication rates [1–3]. A significant complication is ICH which can be fatal in some cases. At our department, between 1999 and 2010, 1070 DBS procedures were performed

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