Intraoperative DSC-MRI (iDSC-MRI): feasibility and clinical application

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Introduction: Dynamic susceptibility contrast MRI (DSC-MRI) enables calculation of regional maps for relative blood volume and flow by administering a bolus of conventional MR contrast agents while T2*-weighted images are being acquired. This technique can thus provide pathophysiologic data and has been used to distinguish high-grade from low-grade tumors as well as to create characteristic maps for lesions such as tumefactive lesions and lymphoma (1-6). As of now this technique has only been used preoperatively for differential diagnosis and both postoperatively and during follow-up to distinguish recurrent disease from radidation necrosis (7, 8). Any preoperatively acquired data can be integrated into a neuronavigation device. However, in the presence of intraoperative brain deformation, so-called brain shift, this preoperative acquired data is no longer valid and the amount of brain shift is unpredictable. Intraoperative MRI was thus introduced to detect residual tumor during the resection while the patient is still under anesthesia and the skull is still open. This enables the neurosurgeon to complete the resection during the same procedure. The aim of this study was to assess the feasibility of DSC-MRI in an intraoperative setting in terms of possible technical drawbacks caused by both the susceptibility of air or an air-water level in the resection cavity and a restricted choice of MR coils and to compare the results with preoperatively acquired maps.

Material and methods: Informed written consent was obtained from all patients and the study was approved by the institutional review board in accordance with the guidelines of the Helsinki Declaration. First, a water-phantom was used with a water-air level while performing the dynamic susceptibility contrast T2*-weighted EPI sequence (TR / TE = 17 / 8 ms; FOV 240 mm; matrix 128x128; EPI factor = 17, number of slices 30 with slice thickness of 3.5 mm) in the MR-OR suite (see below) to assess the artifacts and predict the results of intraoperative imaging. Secondly, we acquired images in a flow phantom consisting of agarose gel (concentration 1.2 %) doped with 300 mg / l Ni-(II)-sulfate. In this model, 4 silicone tubes (2 with an outer diameter of 9 mm and 2 with an outer diameter of 5 mm; wall size 1 mm each) filled with saline were embedded and continuously flushed at a laminar flow. Intraoperative DSC-MRI (iDSC-MRI) was then performed in 6 patients (3 men, 3 women, mean age 71 years, range 55-76 years) with glioblastoma multiforme. The operation room (OR) is equipped with a 1.5-Tesla MR scanner (Philips Intera, Philips Medical Systems, Best , The Netherlands). Outside the 5-Gauss line, standard microsurgical equipment is used for tumor surgery. To connect the OR table and the scanner, a rotating table (modified Angio DIAGNOST 5 Syncra Tilt Patient Support, Philips Medical System, Best, The Netherlands) is used in order to transport patients between the surgical and imaging sites. For surgery the patient`s head is positioned and rigidly fixed to the table using a custom-made MR-compatible carbon-fiber Mayfield head-holder (ProMedics, Duesseldorf, Germany). For intraoperative MRI the table is connected with a specially designed custom-made rail that bridges the gap to the scanner; the operation table can be slid into the bore. For imaging, a flexible two-channel coil system (Philips, Best, The Netherlands) was used, whereby one part was placed below the patient's head at the beginning of the operation and the second part adjusted prior to intraoperative scanning on the craniotomy defect, both draped in a sterile fashion. Data was analyzed using nordicICE software (9; NordicNeuroImaging, Bergen, Norway), including a concentration-time data fit using a gamma-variate function (10-18) after defining the arterial input function (AIF) adjacent to a feeding vessel. To avoid artifacts from recirculation of the contrast agent while scanning, the signal intensity curve was cut off after the first pass. Vessels as depicted on postcontrast T1 were excluded from further analysis (19).

Results: Only minor distortions occurred at the water-air level. In the flow model the susceptibility artifact did not change the shape of the "vessel" but the tube diameter appeared to be twice its actual size. In 5 of our patients the tumor was already completely removed macroscopically by the time intraoperative DSC-MRI was performed as prooven by postoperative MRI and did thus not yield elevated perfusion values. There was no significant susceptibility artifact in the resection cavity, thus enabling us to reliably judge the data. In one case an area at the ventral border of the resection cavity showed both elevated perfusion values and contrast enhancement consistent with residual high-grade tumor, which had also been depicted on preoperative scans. The preoperative rCBF ratio of this 2.7 mm^3 tumor part was 2.03 compared to the contralateral hemisphere, whereas the ratio of the area intraoperatively was 1.96. Compared to preoperative DSC-MRI no significant differences in image quality were found and, despite some brain shift, the area of elevated regional perfusion could be identified on both scans.

Conclusion: Intraoperative MRI offers the option of an early resection control enabling the neurosurgeon to complete the resection if residual tumor is present. Contrast enhancement of a lesion most likely represents tumor tissue, but manipulation in a resection cavity will also influence this phenomenon (20). As confirmed by our results dynamic susceptibility-weighted MRI (DSC-MRI) applied intraoperatively could solve this problem as it provides physiologic perfusion data and appears – based on these preliminary results - technically feasible intraoperatively. Brain shift at this timepoint is not an issue. Distortion caused by the air-fluid level did not impair analysis of the data as demonstrated by both phantom and the patient data, which could easily be performed while the postcontrast T1-weighted sequences were being acquired. Residual tumor tissue could easily be detected; indeed, the pre- and intraoperatively demonstrated perfusion ratios were identical at the same part of the tumor when taking the brain shift into account. As our preliminary results suggest, it appears to be as reliable as the preoperatively acquired information with comparable results, however, further data is needed to prove these results.

References: 1; Knopp et al., Radiology 1999. 2; Law et al., Radiology 2002. 3; Provenzale et al., AJR 2002. 4; Hartmann et al., Neurosci Lett. 2003. 5; Lev et al., AJNR 2004. 6; Boxerman et al., AJNR 2006. 7; Sugahara et al., AJNR 2000. 8; Covarrubias et al. The Oncologist 2004. 9; Emblem et al. Radiology 2008. 10; Villringer et al., Magn Reson Med 1988. 11; Belliveau et al., Magn Reson Med 1990. 12; Rosen et al., Magn Reson Med 1990. 13; Edelman et al., Radiology 1990. 14; Sugahara et al., AJR 1998. 15; Sorensen et al., Radiology 1999. 16; Provenzale et al., AJR 2002. 17; Conturo et al., JMRI 2005. 18; Ostergaard et al., JMRI 2005. 19; Caseiras et al. AJNR 2008. 20; Knauth et al. AJNR 1999.