MRI during Active Neurostimulation at 3T: A Feasibility Study

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INTRODUCTION:

In recent years, MRI examinations to map activity, perfusion and cellular integrity in the human brain, e.g. functional MRI, diffusion MRI and perfusion MRI, have become an inherent part of clinical radiodiagnostics. So far, the benefit of these methods has not been available for patients that have implanted deep brain (DBS) or spinal neurostimulators (e.g. suffering from Parkinson's Disease or chronic pain) because of safety-relevant and methodical concerns. On the one hand, these concerns are related to line surges that are induced into the electrical circuit closed by stimulator, input lead, electrodes and brain tissue by RF-pulses and fast switching gradients (e.g. EPI-sequences). On the other hand, the RF pulse could potentially couple into the input lead acting like an antenna and thus building stationary waves of current density [1]. As a result of induced voltage and involved current flow, heating of brain tissue and stimulation of neurons can take place. Both effects should be avoided, because strong heating causes irreparable damage to brain tissue and untriggered neurostimulation may make fMRI experiments useless.
It has been shown that under certain circumstances MRI examinations during active neurostimulation is harmless for potential patients [2]. To analyze the existence and strength of these effects at 3T systems, the induced voltage and the temperature near the electrodes and their input lead was measured under various conditions. Image quality with respect to RF interferences and susceptibility artifacts was assessed.

MATERIALS AND METHODS:

The studies were performed on a whole-body 3.0T (Trio, Siemens, Erlangen, Germany) scanner. For imaging two different RF coils were available: a receive-only 8-channel-headcoil for parallel imaging and a transmit-receive CP headcoil. The measurement of the line surges was conducted with a digital oscilloscope (Tektronix, Bracknell, UK; max. sampling rate 1GHz). The measurement of the temperature was conducted with a fiberoptic thermometer (Luxtron, Santa Clara, CA, USA; four channels). The stimulating electrodes were placed in a spherical phantom filled with NaCl-solution (0.5%). To register heating near the electrodes and their lead, the temperature probes were placed equally spaced along the electrodes and the lead inside the phantom. There were also probes to monitor the temperature of the environment. The induced voltage was measured at the lead between electrodes and stimulator (Medtronic 3387 and 3625, Minneapolis MN, USA). All measuring instruments and the stimulator were located outside the scanner room. The following sequences were run on the scanner: T2* GE-EPI (RF power for 8channel coil/CP coil = 2.3/14W), diff. weighted SE-EPI (1.7/11W), MPRAGE(1.6/10.2W), T2 TSE (13.7/76W), T1 SE (13.7/75.7W).

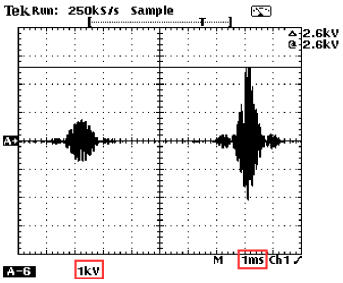

FIG. 1: Voltage across electrode during SE seq; 8channel coil; lead along body coil

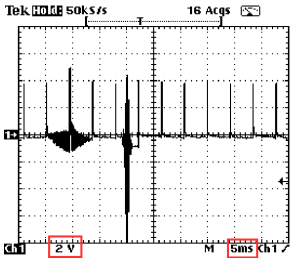

FIG. 2: Voltage across electrode during GE-EPI seq.; voltages superimpose

RESULTS AND DISCUSSION:

The measurement of induction with sequences that have particularly high slew rates (GE-EPI, Diff.w.-EPI) didn't show any line surges induced by switching gradients that differ from noise, either for the transmit-receive or the receice only coil. This is in agreement with calculations whereupon the induced voltage shouldn't exceed 5mV. In contrast to switching gradients, the RF pulses are clearly observable. Depending on the sequence and experimental setting, the amplitudes ranged between less than 10V/2V (GE-EPI; lead along the scanner's symmetry-axis, 8channel coil / CP coil respectively) and far more than 2.6kV/17.2V (SE; lead next to the RF coil; 8channel/CP) (FIG. 1). The coincidence of stimulation and RF pulse causes deformation of the stimulation pulse (FIG. 2). Loops in the lead result in higher voltage amplitudes. In the range of some Volts one doesn't have to assume physiological reactions since the carrier frequency of the RF puls (126MHz) is too high to excite action potentials of neurons [3].

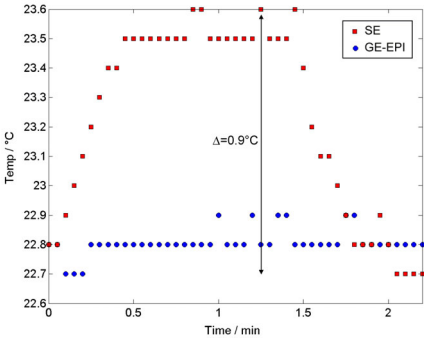

FIG. 3: Temp. increase during GE-EPI and SE seq; CP headcoil; lead along symmetry axis

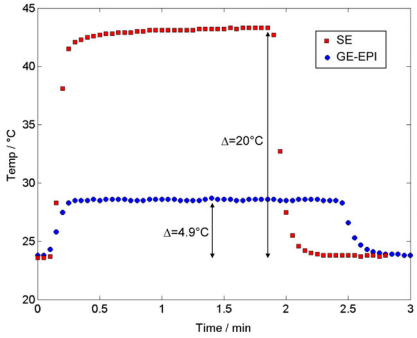

FIG. 4: Temp. increase during GE-EPI and SE seq; 8channel coil; lead along body coil

The temporal progression of temperature at the electrodes as well as at the lead depends very much on the RF power of the sequence and the particular setup. When the lead was placed along the scanner's z-axis there was no noteworthy heating within the accuracy of measurement (0.1°C) for the low-power sequences and heating of less than 1°C for the high-power sequences for both RF coils (FIG. 3). When the lead was placed near the RF coil, however, spontaneous heating took place at the electrode and its conecting lead. The increase in temperature depended on the used RF coil, the exact position of the lead relative to the coil, and the RF power of the sequence. The highest increase (20°C) at the electrode could be observed during SE imaging with the 8channel coil (FIG. 4). Even during GE-EPI an increase of 4.9°C at the electrodes could be observed. In this setup significantly lower temperature increase was measured (0.8°C/3.5°C) when the transmit-receive CP coil was used.
The acquired images showed artifacts from transitions in susceptibility. The strongest deletions were visible, as expected, for the GE-EPI sequence. RF interferences could also be observed. However, these images can still be used for data analysis, except in the immediate vicinity of the electrode and the lead.

CONCLUSION:

The studies show that MRI examinations with fast EPI and MPRAGE sequences in principle may be performed on patients with implanted active neurostimulators at 3T scanners. When the lead is placed along the symmetry axis of the scanner heating of electrodes and lead cannot be observed at sequences that are relevant for clinical functional imaging. Induced voltage also cannot harm patients. When the lead is placed near the RF coil, however, one can observe extensive spontaneous heating and high induction voltage. These effects also depend on the applied RF power. They can lead to serious hazzards for the patient. Due to its lower RF power, the transmit-receive coil causes lower induced voltage and temperature rise. Therefore, it should be used rather than a receive-only coil, that needs the body coil for transmission.
Before patient examinations are carried out on other scanners the presented results have to be reproduced for the setup at the particular site!

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