

IMPLANTED DEEP BRAIN STIMULATOR AND 1.0 TESLA MAGNETIC RESONANCE IMAGING

(Clinical notes)

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ABSTRACT

There is a great need for magnetic resonance imaging (MRI) examinations of patients who have previously undergone deep brain stimulator (DBS) implantation. The current guidelines pertain only to a 1.5 Tesla horizontal-bore scanner complying with strict safety regulations. Moreover, almost all published in vitro and in vivo studies concerning patient safety are carried out on 1.5 Tesla MR scanners.

The aim of our work is to share our clinical experience of 1.0 Tesla brain MR imaging. During the past 4 years, 34 patients with different types of implanted DBS systems underwent 1.0 Tesla MR examinations to answer diagnostic or clinical questions. Apart from the scanner type applied, all other safety instructions were strictly followed.

The MRI itself made no significant difference to the measured impedances or the stimulation parameters required to achieve the optimal therapeutic results. From theoretical considerations, it may be assumed that 1.0 Tesla MRI can be performed safely on DBS-implanted patients, provided that all other recommendations are adhered to.

Keywords: deep brain stimulation; magnetic resonance imaging; safety; implants.

INTRODUCTION

Clinical and scientific considerations sometimes lead to neurologists feeling the pressure to have brain magnetic resonance imaging (MRI) performed on patients with an implanted deep brain stimulator (DBS). The growing number of published cases describing either temporary or permanent neurological deficits related to MRI (1,2) point to the importance of adherence to the safety guidelines. Although no adverse results have been seen to date if all safety regulations are followed (3,4), these reported incidents have resulted in the manufacturer revising the safety guidelines toward an increased level of caution (3,5).

The safety of the imaging of DBS-implanted patients with MR systems operating at field strengths other than 1.5 Tesla has not been established (3,4). Spiegel et al. recently reported transient dystonia following 1.0T MRI in a 73-year-old Parkinsonian patient (2). In that case, the bilaterally implanted electrodes (subthalamic nuclei) were externalized and not connected to the impulse generator (IPG). In the absence of a control MRI, from the clinical presentation alone, Spiegel concluded that the transient neurological adverse reaction observed was due to the MR examination itself. If the implanted system has broken leads or the externalized cables are not coated with insulating material, the chance of overheating is higher (3). However, the question remains open as to whether uncoated externalized electrodes or the use of a 1.0T MR scanner or both led to that incident. Moreover, neither the head SAR nor the gradient switching used during the MRI procedure was mentioned in that case-report, though these too might have also played a considerable role in the development of the incident.

Recently, another injury was reported following the use of 1.0T MR (Expert, Siemens Medical Solutions), which was completely different in nature from the

previous one (1). In consequence of drug-resistant idiopathic Parkinson's disease (PD), the patient received bilateral Soletra implants into the subthalamic nuclei. Since he was an avid hunter, the left IPG was implanted not in the conventional infraclavicular region, but in his abdomen to avoid interference with the butt of his rifle. Later, the patient underwent spinal MRI because of back pain. Immediately after the procedure, newly developed skew-deviation and right-sided hemiplegia were noticed. Computer tomography of the brain revealed intracranial hemorrhage surrounding the left electrode. A number of simultaneous violations of the guidelines were suspected in the background of the incident: a transmit/receive body radiofrequency (RF) coil was applied instead of a transmit/receive head RF coil; the whole-body-averaged SAR was estimated to be between 0.57-1.26W/kg, with local values up to 3.92W/kg (1); finally yet importantly, the operating mode of the DBS was unknown. Thus, it is feasible that the DBS might have been active during the procedure.

All present safety recommendations were developed for brain MRI in patients with turned-off IPGs implanted in the infraclavicular region. Since spinal MRI was performed and the left Soletra IPG was situated in the abdomen, the IPG and its connecting leads could receive direct and long-lasting electromagnetic (EM) waves, which increased the chance of tissue damage around the left electrode. However, similarly as in the previous case, it cannot be decided whether the field strength of the scanner was the cause of the incident, or whether all other factors would themselves have been enough.

Current safety regulations relate to, and prior in vitro and in vivo studies have been performed at, the more common clinical 1.5T field strength. However, some centers of necessity perform MR examinations with various devices that have not

been previously tested. Certain theoretical considerations suggest that 1.0T MRI might be performed safely on patients with implanted DBSs if all other safety recommendations are complied with.

MATERIALS AND METHODS

Patients

Thirty-four patients (mean age 56.9 years) with either unilaterally (Solettra: n=16) or bilaterally (Kinetra: n=17, bilateral Solettra: n=1) implanted DBSs underwent 1.0T brain MRI. Indications for DBS therapy included PD (n=24), essential tremor (n=6), primary generalized dystonia (n=2), multiple sclerosis (n=1) and an unknown type of tremor (n=1). Before the examinations, written informed consent was obtained from each patient as demanded by the Hungarian regulations.

Measurements

The MR images were acquired on a Siemens Magnetom Harmony 1.0T scanner (Siemens, Erlangen, Germany). The number of applied sequences was set to the minimum. To analyze the anatomical situation and calculate the electrode positions, an axial T1-weighted MP-RAGE sequence was applied (slice thickness: 2mm without gap, repetition time: 2120ms, echo time: 3.92ms, inversion time: 1100ms, flip angle 15, SAR: 0.038W/kg, gradient switching: 19.87Tesla/s, Syngo MR 2004A 4VA25A, head transmit/receive coil). If the clinical situation required it (n=28), a T2-weighted sequence was also used (slice thickness: 6 mm, gap: 0.9 mm, repetition time: 5000, echo time: 85, flip angle 180, SAR: 0.1968W/kg, dB/dt: 14.35). As the MP-RAGE and T2-weighted images satisfactorily answered the clinical questions, no other sequence (FLAIR, fat saturation or diffusion-weighted

imaging) was used.

All examinations were carried out postoperatively, between 2 weeks and 1 year after IPG implantation. Besides the applied scanner, the MRI procedure exactly followed the previous (5) (until 2002) or the current (since 2005) guidelines (3) of the manufacturer. Before examinations, the impedance of the contacts was checked; the IPG was programmed to meet the recommendations and then turned off. During the MRI procedure, all the patients were awake and continuously monitored for any adverse effects. Subsequently, physical examination, questioning concerning adverse effects, checking and reprogramming of the DBSs was performed. To test for subclinical changes in the DBSs, the impedances of each active contact before and after the MR examination were compared. For statistical analysis, the paired t-test was applied.

RESULTS

None of the patients reported strange feelings or signs during or after the MR procedure. Thorough neurological examinations did not reveal any previously unreported symptoms related to the MR scanning.

Before examinations, the impedances exhibited large individual differences probably originating from the heterogeneous etiologies, target locations, electrode types, IPG types, and the large variability in the time elapsed between the operation and the MRI examination. However, comparison of the pre- and post-MR impedances revealed no significant change (1128 ± 457 vs. 1152 ± 501 , $p > 0.05$). The therapeutic effect of the DBS system also remained unchanged since the same symptom relief could be achieved with unchanged stimulating parameters.

DISCUSSION

Deep brain stimulation is a technique widely used to treat certain movement disorders. Since the IPG, the electrodes and the connecting cables can interfere strongly with the various magnetic fields generated by the MR scanners, the patients are potentially exposed to danger (4,6). The most important hazards to deal with are the heating, the induced voltage, displacement of DBS elements and the reprogramming/turning-off of the DBS (6,7). Current guidelines pertain only to 1.5T horizontal bore MR scanners (3,5). However, since a 1.5T scanner was not available in our region, after consultation with the patients we decided to perform imaging with a 1.0T scanner. Unfortunately, we found no literature reports relating to in vitro evaluations of the use of 1.0T scanners. After the thorough consideration of each of the major factors, we concluded that, at least theoretically, 1.0T MRI could be safe.

1. Since the static field strength has a direct impact on the forces and torque experienced by an implanted DBS system during MRI, a 1.0T scanner can generate less forces and torque than those with a 1.5T scanner.

2. One of the main differences between 1.0T and 1.5T imaging is the excitation RF (42.6MHz and 63.9MHz, respectively). The lower frequency at 1.0T results in a smaller mean SAR for a particular flip angle. The mean SAR will, therefore, be lower at 1.0T than at 1.5T, provided the readout bandwidths, matrix sizes, etc. are kept constant.

3. In certain situations, the high gradient switching can induce potentially harmful current in the electrodes; therefore, the 20T/s safety limit has to be followed at 1.0T MRI.

4. The resonant coupling (RC) of the RF power into the connecting lead between

the IPG and the electrodes is the mechanism that involves the greatest risk of heating (8). The power absorbed on the antenna is proportional to its radiation resistance, which is dependent on the wavelength and configuration, but not on the material of the antenna (9). The RC occurs only if the length of the lead and the connections reaches or exceeds half the wavelength of RF field. The wavelength is assumed to be ~46cm at 63.9MHz (^1H Larmor frequency at 1.5T) and ~70cm at 42.6 MHz (^1H Larmor frequency at 1.0T) (7). Therefore, the possibility of overheating is higher at 1.0T MRI (8).

The implanted electrode and connecting wires may have an equivalent linear antenna length of 20-50 cm, depending on the configuration. The absorbed power and its dependence on wavelength can be estimated via analytical calculations on a linear antenna with planar EM waves. This approach provides an upper limit estimation for the absorbed power without an exact knowledge of the configuration or the length of the connecting wires.

The radiation resistance has its maximum and minimum at specific L/λ values, depending on the resonance conditions (L is the length of the linear antenna and λ is the wavelength of RF EM waves). The ratio of the delivered powers, $P_{1.0T}/P_{1.5T}$, is equal to the ratio of the corresponding radiation resistances. This ratio cannot exceed 2.6 in any L/λ regime. The realistic regime $0 < L/\lambda < 3$ is illustrated in **Figure 1**. Reduction of SAR to $1/2.6$ ($\approx 38\%$) takes care of the possible increase in transmitted power due to the altered L/λ on switching from a 1.5T magnet to a 1.0T magnet. In our studies, therefore, SAR was reduced from 0.4 W/kg to 0.1 W/kg.

These theoretical considerations led us to assume that 1.0T MR examinations might be performed at an acceptable risk. To minimize the occurrence of

unwanted adverse interactions, stricter precautions were taken than the currently recommended guidelines:

Since the broken electrodes are more likely to undergo excessive overheating, the impedance of each electrode was checked. Afterwards, the IPGs were programmed according to the recommendations and then turned off before the MRI.

A transmit-and-receive-type head RF coil was applied, while the limit for the gradient switching used for MRI was also lowered to $<20\text{T/s}$. The lowest possible head specific SAR was achieved. At the time of the first examinations, the highest allowed SAR value was the 0.4W/kg set by the manufacturer (5). However, we set the head specific SAR to $<0.1\text{ W/kg}$ (10).

All of the patients were informed about the possible risks, and their written informed consent was then obtained as required in our country. During the MRI procedure, the patients were awake and continuously monitored. They were also asked to report any strange feelings during or after the examination.

During the past four years, 1.0T brain MR examinations have been performed on 34 patients with various implanted DBS systems in our centre. With the described method, we did not observe any adverse reactions relating to the MRI. Analysis of the pre- and post-examination impedances did not indicate either electrode fracture or appreciable electrode dislocation.

We consider that 1.0T MRI is safe if all instructions are respected. In the incidents described earlier, several other factors (i.e. non insulated electrodes, unconfirmed and possibly incorrectly adjusted head SAR and dB/dt values, a wrong type of RF coil, an unknown operation mode and the intraabdominal implantation of an IPG) were likely to have played a more important role in the resulting injury than the use

of a 1.0T scanner instead of a 1.5T scanner.

Naturally, we do not believe that MR examinations should be performed without prior in vitro experiments to quantify potential hazards, though, the clinical situation may sometimes demand this. Despite the fact that our postoperative 1.0T brain MRI examinations did not involve any obvious adverse reaction in any of the cases, this does not mean that our method is entirely safe. However, it should encourage experts to carry out in vitro evaluations with the parameters that we applied, because this procedure might turn out to be as safe as that with the current 1.5T guidelines.

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LEGENDS

Figure 1. Theoretical curve demonstrating the absorbed power ratio for linear antennas with sinusoidal current distribution as a function of L/λ . The exact equivalent length of the linear antenna (L) is unknown, since it depends on the configuration, but it can reasonably be assumed to be $<3\lambda$ (λ is the wavelength of RF EM waves). The value of λ depends on the electrical permittivity of the tissue. The realistic L/λ regime is 0-3. The antennas are considered identical except for the difference in their L/λ values according to the Larmor frequency differences for 1.0T and 1.5T magnets.

