Interaction between grounding pads used for RF ablation therapy and magnetic resonance imaging

Abstract Objectives: To characterize artifacts and imaging problems in the presence of conductive grounding pads for RF ablation therapy as well as potential heating problems due to induction of eddy currents in the pads. Strategies for avoidance of those problems are developed. Materials and methods: Underlying principles of interactions between grounding pads and MR imaging are reported. Influential parameters, e.g., orientation in relation to the magnetic field, shape of the grounding pad, sequence type (spin-echo versus gradient-echo) and magnetic field strength (0.2 T, 1.5 T, 3 T) were varied in systematic phantom studies. Heating effects due to induced eddy currents were estimated theoretically and measured by infrared imaging in an adapted set-up. Results: MR imaging artifacts are markedly dependent on the orientation and geometrical shape of the grounding pads. Visible signal extinction artifacts were more pronounced using spin-echo techniques than in gradient echo images and increased for higher field strengths. Suitable incisions in the grounding pad reduced eddy currents markedly and minimized image artifacts. Heating problems due to induced eddy currents by the RF transmitted for MR imaging were excluded by phantom measurements. Conclusions: Suitable positioning of the grounding pads and adaptation of their geometry provide clearly reduced artifacts in MR imaging.

Keywords Interventional MRI · Radio frequency ablation · MR artifacts · RF interactions

Introduction

Image-guided percutaneous radiofrequency ablation serves as a minimally invasive interstitial thermo-therapy of deep-seated pathologic tissue and has gained increasing importance within the recent years [1–6]. With the introduction of open magnet technology, progress in fast imaging techniques and the development of MR-compatible RF devices MR-guided treatments have become clinically feasible [7]. MRI provides high intrinsic soft tissue contrast allowing for near-online monitoring of the coagulation procedure. In addition, MRI enables navigation of RF applicators through multiplanar imaging capabilities.

The basic principle of RF heating is based upon an alternating electrical field emitted from the active tip of a needle electrode. The RF generator typically provides a frequency of 500 kHz. Induced ion agitation in biological tissue is subsequently converted by friction into heat. This process is used to create well-defined zones of coagulation necrosis. The application of the radiofrequency energy can be performed with either monopolar or bipolar techniques. Monopolar technique is more commonly used for tumor ablation because it provides a more spheric lesion geometry compared to multipolar devices [1]. In addition, positioning of only one active electrode inside the target tissue is less time-consuming and less invasive.
Monopolar technique requires the electric circuit to be completed by placing grounding pads on the patient’s skin. Aluminum is often used as electrically conductive material in such grounding pads as this material, with its very low magnetic susceptibility of $\chi_S = 12 \times 10^{-6}$ close to that of human tissue and water, does not markedly disturb the static magnetic field. For this reason, distortion artifact as known from paramagnetic or ferromagnetic implants does not occur in tissue regions near the grounding pads. However, interferences with the radio frequency field of the imager used for spin excitation either by amplifying or by reducing the local flip angle may occur locally in the surrounding of the metallic object.

To reduce imaging artifacts, it would be desirable to place the grounding pad outside the scanning area. However, to assure an acceptable size of necrosis and to prevent from uncontrolled electric current pathways through the body, it is necessary to place the grounding pads close to the active tip of the RF applicator. Furthermore, the surface of a grounding pad applied for RF ablation must have a certain minimum area, since considerable RF currents between active electrode and grounding pad must be possible without risk of skin burning [10, 11].

The aim of the presented study was to analyze image artifacts in MRI caused by eddy currents induced by the RF field of the MR unit inside the grounding pads. Potential strategies for avoidance or correction of those undesired effects are proposed.

Effects from the RF field transmitted by the RF ablation unit (which is usually not active during MR imaging) and interactions with the cable attached to the grounding pad are not considered in the present work.

Since RF fields can be sources of heating effects in metallic objects or in the surrounding tissue [12, 13], the characteristics of induced eddy currents were estimated using a numerical model and possible effects were assessed by experiments with an infrared camera.

**Materials and methods**

Eddy current induction in the grounding pad caused by the RF field of the MR scanner

High-frequency electromagnetic fields during an RF pulse may induce electric currents in two-dimensional well-conducting structures [9]. The basic principles of this process are shown in Fig. 1: The circularly polarized alternating $B_1$-field ($B_{1x} \sin \omega t + B_{1y} \cos \omega t$) leads to eddy currents ($I_{eddy}$) inside the conductive material of the grounding pad due to Faraday’s law of induction. These currents are associated with magnetic fields ($B_{1x, eddy}$ and $B_{1y, eddy}$) superimposing the original $B_1$-field. Depending on the phase relations of the superimposed components, amplification or attenuation of the effective RF field $B_1$ (and consequently on the applied excitation angle in an imaging sequence) might occur locally in the surrounding of the metallic object.

![Fig. 1 Induction of eddy currents in the grounding pad. The relationship between electric and magnetic fields is demonstrated. The circularly polarized alternating $B_1$-field (with components $B_{1x}$ and $B_{1y}$) might induce eddy currents ($I_{eddy}$) inside the conductive material of the grounding pad. These currents are associated with secondary RF magnetic fields ($B_{1x, eddy}$ and $B_{1y, eddy}$) superimposed on the original $B_1$-field irradiated for spin excitation either by amplifying or by reducing the local flip angle.](image)

Therefore, altered signal yield and contrast behavior must be expected near the grounding pads due to alterations of the RF intensity and resulting flip angles of RF pulses. In order to demonstrate how varying excitation angles influences contrast behavior, four images of a volunteer’s kidney with a renal cell carcinoma and a renal cyst were recorded. In order to achieve defined conditions (that means defined flip angles) no grounding pad was fixed on the patient. Instead, excitation angle was altered by manually reducing the transmitter voltage that is normally adjusted by the built-in routine of the MR scanner (see Fig. 4).

Numerical calculation of current density and $B_1$ field distribution

A special software (FEKO 4.3, Software & Systems-S.A. Ltd, Stellenbosch, South Africa) was used to calculate the current density inside the aluminium pad and the actual local $B_1$ field strength. Calculations were based on a numeric model under the following assumptions:

An aluminium pad (dimensions: $155 \times 70 \times 0.05$ mm$^3$; specific conductivity $\sigma = 3.8E+07$ S/m, relative permeability $\mu = 1.0$) is exposed perpendicular to a linearly polarized alternating magnetic field $B_1$ (maximum amplitude: $50 \mu T$; frequency: $8.0$ MHz at $0.2$ T, $63.8$ MHz at $1.5$ T, $123$ MHz at $3$ T).

**Experimental**

**Characteristics of commercial grounding pads**

Commercially available grounding pads usually consist of three layers of different materials. An often applied grounding pad is the single use electrode from Valleylab (Tyco Healthcare Group LP, Boulder, Colorado, USA) with a size of $155 \times 70 \times 0.05$ mm. Three layers consisting of contact gel, metallic film, and cellular...