Although the title of this text implies that the subject is a broad range of safety issues related with all electrophysiology procedures (EP), here only the radio-frequency (RF) pulse related safety issues during the MR-guided EP procedures will be discussed.

In an engineering perspective, EP procedures may be described as invasive methods of evaluating the electrical system of the heart and ablating portions of tissue that causes arrhythmia. Currently, most EP procedures are conducted under X-ray fluoroscopy guidance. During these long procedures, high exposure to ionizing radiation is a significant issue for patients and interventionalists but more importantly low soft tissue contrast limits the capability of interventionalist in conducting difficult EP procedures. MRI with no ionizing radiation offers high tissue contrast and ability to monitor tissue during the ablation procedure (1-3).

MRI also comes with several drawbacks. Conventional MRI scanners are not designed to handle real-time operations. It is difficult to visualize the catheters and guidewires used during the procedures. Time varying magnetic fields used during MR imaging interacts with EP signals. All of these problems are under investigation and partially solved by engineers and scientist working on the MR technology. One other problem, the excessive unwanted heating of the body due to radiofrequency (RF) pulses used during the imaging procedure remains as a significant challenge (4).

Main issue related with the RF heating problem is that the transmitting (typically body) coil induces high currents on the metallic elongated structures such as guidewires and catheters and causes high current density in the tissue around the distal end (tip) of these devices. Because of this high current, the specific absorption rate (SAR) around the tip of the metallic devices may exceed recommended limits. In some extreme cases, this current may cause unwanted tissue damage.

In order to address this problem, researchers have investigated the relationship between the level of the RF pulse and the amount of tip heating. The EP catheters and guidewires are resigned to minimize the induced currents on them. Novel technologies are developed to monitor the amount of tip heating during MRI procedure in order to control applied RF power level. In addition, transmitting coils and their RF pulses are designed to minimize the induced currents.

RF current induction on the long metallic wires

It is well-known that electric and magnetic field are coupled to each other. One may not be able to obtain pure time-varying magnetic field without any electric field in a given volume of interest. Ideally, an MR experiment should be conducted using only combination of time varying and static magnetic fields. Unfortunately, when creating these magnetic fields, undesired electric field also forms. One of the engineering tasks is to keep this electrical field under control since it causes unwanted power deposition in the body (5). If the power is not under control, the power may lead to excessive heating, hyperthermia and/or tissue damage.

Although determining the exact amplitude and phase of the electric field inside the body is a difficult task, it is known that when a birdcage coil is used in quadrature excitation mode (this is the case in most if not all scanner (6)), the electric field is highest close to surface of the body and low deep inside the body. The electric field strength is approximately proportional with the radial position of the point of interest and it is mainly along the z-direction. The detailed calculations using electromagnetic simulations show this general tendency but also reveal some significant variations especially around bones.

In the presence of long metallic wires inside the body, the component of the electric field along the wire is the source of the current induction. If this induced current is not kept under control, a very high temperature rise may be observed (7). Experiments and calculations showed that this high temperature occurs at the distal end of the catheter, typically at its electrodes (8).

Our group has formulated relationship between incident electric field (the electric field in the absence of the catheter) and the current along the catheter using a modified transmission line (MoTLiM) theory (9). In this method, the electrical properties of the catheter can be modeled using only two parameters: wave number and series impedance per unit length. Note that these numbers depend on the insulation thickness, winding of the conductors. Using these two numbers and the incident electric field, the current on the catheter can be calculated for any given catheter length.The MoTLiM formulation, and earlier experimental and simulation studies show that under a uniform electric field maximum tip temperature rise occurs at a specific length of the catheter. This length is usually formulated as the resonance length. We also showed that when the phase of the incident electric field varied in accordance with the wavenumber, even higher tip temperature rise may be observed (10).

Safe EP catheter design

There are a number of designs for reducing the catheter tip heating problem. For example, Susil et al (11) proposed using inductors at the distal end of the catheter just before connecting the electrode wires to the electrode. This ensures RF current isolation between catheter and its electrodes. Note that inductors at the distal end of the catheter is basically short circuit at low frequencies and therefore sending the ablation signal (also called RF signal but typically at much lower frequency around 50kHz) and recording intracardiac ECG signal are possible. The MoTLiM formulation (9) shows that other way to reduce the tip heating is to use designs that have high wavenumber values. This can be achieved by, for example, using multiple windings (12) and/or using proximity effect (work on this subject will be presented by V. Acikel and E. Atalar)

One complementary approach is to use temperature sensors at the tip of the catheter (13). If unwanted temperature rise occurs because of the failure of the design, it is feasible to stop the scan or reduce the applied power level.

Safe RF excitation

It is interesting to note that while minimization of the induced RF currents on the catheters/guidewires is possible by modifying the devices, it is also possible to reduce the induced currents by modifying the electric field distribution. In fact, it was shown by our group that by transmitting RF pulses using the linear mode of the birdcage coil, it is possible to obtain a plane with zero electric field (14). Since it is possible to rotate the linear polarization direction, it is possible to control the location of this zero electric field plane. If a catheter lies in this plane, there will be no induced current on it and therefore there will be no heating. This idea was extended to include catheters that do not lie in a particular plane. By modifying the polarization of the excitation, it is possible to obtain no noticeable heating at the tip of the electrode and still obtain uniform excitation (15).

In short, the MR related safety of the MR guided EP procedures can ensured if the problem is very well analyzed and proper solutions are used.

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