MRI Induced Heating on Pacemaker Leads

Eugenio Mattei
Istituto Superiore di Sanità, Italy

Giovanni Calcagnini
Istituto Superiore di Sanità, Italy

Michele Triventi
Istituto Superiore di Sanità, Italy

Federica Censi
Istituto Superiore di Sanità, Italy

Wolfgang Kainz
Center for Devices and Radiological Health, Food and Drug Administration, USA

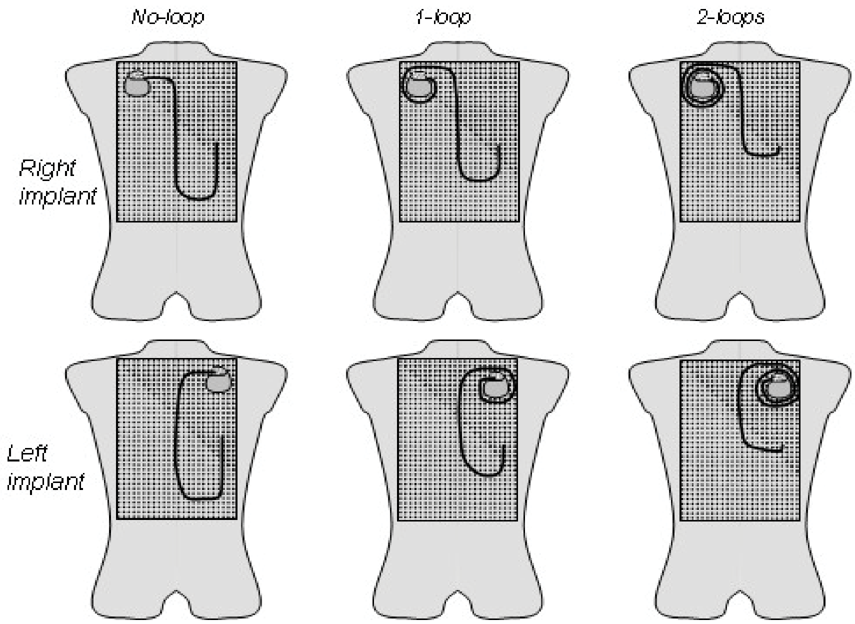
Howard Bassen
Center for Devices and Radiological Health, Food and Drug Administration, USA

Pietro Bartolini
Istituto Superiore di Sanità, Italy

INTRODUCTION

Magnetic resonance imaging (MRI) is a widely accepted tool for the diagnosis of a variety of disease states. The presence of a metallic implant, such as a cardiac pacemaker (PM), or the use of conductive structures in interventional therapy, such as guide wires or catheters, are currently considered a strong contraindication to MRI (Kanal, Borgstede, Barkovich, Bell, Bradley, Etheridge, Felmlee, Froelich, Hayden, Kaminski, Lester, Scoumis, Zaremba, & Zinninger, 2002; Niehaus & Tebbenjohanns, 2001; Shellock & Crues, 2002). Potential effects of MRI on PMs' implantable cardioverter defibrillator (ICDs) include: force and torque effects on the PM (Luechinger, Duru, Scheidegger, Boesiger, & Candinas, 2001; Shellock, Tkach, Ruggieri, & Masaryk, 2003); undefined reed-switch state within the static magnetic field (Luechinger, Duru, Zeijlemaker, Scheidegger, Boesiger, & Candinas, 2002); potential risk of heart stimulation and inappropriate pacing (Erlebacher, Cahill, Pannizzo, & Knowles, 1986; Hayes, Holmes, & Gray, 1987); and heating effects at the lead tip (Achenbach, Moshage, Diem, Bieberle, Schibgilla, & Bachmann, 1997; Luechinger, Zeijlemaker, Pedersen, Mortensen, Falk, Duru, Candinas, & Boesiger, 2005; Sommer, Vahlhaus, Lauck, von Smekal, Reinke, Hofer, Block, Traber, Schneider, Gieseke, Jung, & Schild, 2000). In particular, most of the publications dealing with novel MRI techniques on patients with implanted linear conductive structures (Atalar, Kraitchman, Carkhuff, Lesho, Ocali, Solaiyappan, Guttman, & Charles, 1998; Baker, Tkach, Nyenhuis, Phillips, Shellock, Gonzalez-Martinez, & Rezai, 2004; Nitz, Oppelt, Renz, Manke, Lenhart, & Link, 2001) point out that the presence of these structures may produce an increase in power deposition around the wire or the catheter. Unfortunately, this increased local specific absorption rate (SAR) is potentially harmful to the patient, due to an excessive temperature increase which can bring living tissues to necrosis. The most direct way to get a measure of the SAR deposition along the wire is by using a temperature probe: the use of fluoroptic® thermometry to measure temperature has become "state-of-the-art," and is the industry standard in this field (Shellock, 1992; Wickersheim et al., 1987). When the investigation involves small objects and large spatial temperature gradients, the measurement of the temperature increase and of the local SAR may become inaccurate, unless several precautions are taken. It seems obvious to: (1) evaluate the error associated with temperature increase and SAR measurements; (2) define a standard protocol for probe positioning, which minimizes the error associated with temperature measurement.

Figure 1. Sketches of the six implant configurations tested in a commercial MRI using the human-shaped phantom; no-loop, one-loop, and two-loop for both right and left pectoral implants



BACKGROUND

In most publications dealing with heating of conductive structures during MRI, the reported temperature increase is significantly different, even in cases where the experimental set-up is apparently similar. For example, Achenbach et al. (1997) reported a temperature increase of 63.1°C for a PM lead; Rezai, Finelli, Nyenhuis, Hrdlicka, Tkach, Sharan, Rugieri, Stypulkowski, and Shellock (2002) observed 25.3°C at the end of a deep brain stimulation electrode; Roguin, Zviman, Meininger, Rodrigues, Dickfeld, Bluemke, Lardo, Berger, Calkins, and Halperin (2004) reported a maximum increase of 5.7°C at 3.54 W/Kg whole body specific absorption rate (WB-SAR). Sommer et al. (2000), with a WB-SAR of 1.3 W/Kg, obtained temperature increases ranging from 0.1 to 23.5°C, depending on the electrode type. Several factors influence the degree of heating: (1) the WB-SAR has been shown to correlate to the temperature increase; (2) the cooling effect of the blood around the leads is generally not quantified; (3) the length and the geometric structure of the lead; and (4) the implant location.

In addition, since thin linear structures such as PM leads may generate temperature gradients which cannot be neglected, with respect to the physical dimension of temperature probes, also the relative positioning of the temperature probe to the lead tip significantly affects the measurement, and partially explains the inconsistency of the results in literature.

The aim of this article is first to identify the optimal positioning of fluoroptic® probes to measure the maximum heating of the tip of a PM lead. Then, we use these results to perform measurements in a real MRI system, in order to investigate the effect of the placement of the PM, and of the lead geometry.

MEASUREMENT OF TEMPERATURE AND SAR

We used two experimental setups: first, we performed temperature measurements on a PM lead tip inside a rectangular box phantom, using different types of contact positions between the probe and the lead tip. Second, we used a human-shaped phantom with a PM, and its leads exposed to a commercial MRI scanner.