MRI Safety: RF Burns-Causes And Prevention

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Introduction

Advances in the field of imaging technology have made magnetic resonance imaging (MRI), available to medical science. MRI is a powerful and versatile diagnostic tool, with the consequence of increasing popularity in its use. Developments in MRI technology have only added to increased application of MRI as a diagnostic tool across all kinds of patient populations. A vast majority of MRI examinations pass off without any untoward incident to the patients. However, the interaction of MRI technology with the human body cannot be deemed to be totally safe, with incidents of harm occurring in some cases of MRI examinations (Stokowski, 2005). Bio-effects of MRI refer to the biological effects that occur to the human body, as a result of the interaction between the magnetic resonance (MR) scanner and the human body. These bio-effects can be classified into three, namely, the static field effects, the time varying field or the gradient, and the radio-frequency (RF) effects. Tissue heating can occur through excessive RF interaction in patients, leading to RF burns (Liney, 2010). This paper evaluates the causes for RF burns and the preventive measures that can be taken to reduce the incidence of RF burns.

Heat Stress in RF Technology in MRI

According to Shellock 2000, p.30, "Radiofrequency (RF) energy is non-ionizing, electromagnetic radiation in the frequency range 0-3000 GHz." Evidence from more than three decades of research has demonstrated that RF radiation exposure can have many physiological impacts in the human body. These physiological effects are essentially caused by the RF-induced tissue heating in the human body. During MRI diagnostic examinations, a large portion of the RF energy employed in imaging or spectroscopy gets converted into thermal energy in the tissues of the individual under investigation, due to resistive losses. Therefore, the main bio-effects due to the RF radiation used in MRI technology are a direct consequence of the thermogenic qualities of this electromagnetic field (Shellock, 2000).

Potential risks for individuals in diagnostic imaging using MRI technology relate to the individuals under imaging evaluation and those individuals close to the MRI imaging device, stemming from exposure to the static magnetic field (B0), magnetic field gradients of time variance (dB/dt), and radio frequency (RF) magnetic fields (B1). The important issues relating to safety of RF fields during MRI diagnostic imaging pertain to thermal heating, that results in current burns and contact burns from the heat stress that is generated. Irrespective of the frequency, induced currents cause power dissipation in the tissues of the human body, which results in the build up of energy and increase in the temperature of the body. At frequency levels over 0.1 MHz the thermal impact is more pronounced that has a strong bearing on the safety issues with MRI diagnostic imaging. There is uneven distribution of the RF field, as in-in-homogeneity is enhanced, when the strength of the field is raised, depending on the design of the coil (MHRA Device Bulletin, 2007). Table – 1 gives typical field strengths and RF transmit frequencies for MR systems.

Table – 1 Typical Field Strengths and RF Transmit Frequencies for MR systems

Field Strength (T)	Transmit Frequency (MHz)
0.2 8.5	
0.5 21	
1.0 42	
1.5 63	
3.0 126	

(MHRA Device Bulletin, 2007)

The consequence of absorption of energy from RF fields in the human body is an increase in vibration of molecules and heat generation. Within the tissues of humans the resultant reaction is dilation of the arteries and veins, which leads to enhancement in blood flow in the tissues, and dissipation of the extra heat, through dissipation predominantly through the skin. Different organs in the human body do not have the same electromagnetic and thermal nature. In the case of the human eye there is scanty blood flow and hardly any in the eye lens. The result of low or negligible blood flow means that heat dissipation from the eye will take considerably more time. In the case of the testes ,which separated from the main part of the body, the temperature is usually a few degrees lower than that of the body. It is considered a heat sensitive organ of the human body.

heat sensitive organ of the human body. The thumb rule for increase in body temperature is that in a normal healthy individual a rise of one degree Centigrade does not give room for concern. A key factor to be taken into consideration in rise in temperature in any region of the body is the dependence of the actual rise in temperature on the interaction between the assimilated energy and the energy moved out from the region of the body. Thus the ambient temperature, air flow, clothing and humidity have a strong influence on heat dissipation rate and thus on the rise in temperature (MHRA Device Bulletin, 2007).

According to the conclusions of the 2004 ICNIRP report with regard to RF exposure, in the case of full body RF examinations, negative health impacts are not expected, when increase in the core body temperatures do not increase by more than one degree centigrade. For infants and other individuals with impairments of the cardio-circulatory system and pregnant women, the temperature should increase more than 0.5 degrees Centigrade. Adverse health affects can be avoided in the head regions, when temperatures are maintained at below 38 degrees Centigrade; in the body trunk, when temperatures are kept below 39 degrees centigrade and in the limbs, when temperatures are kept below 40 degrees Centigrade (MHRA Device Bulletin, 2007).

When hazards are present in the use of devices, it is common to have normal operating
modes and other operating modes. It is the same with monitoring and control of RF heating issues with MRI. The normal operating mode refers to the machine parameters that do not present any hazards, while in the first operating mode there is the element of minimal hazard, but not serious to the patient, which requires medical supervision to prevent additional stress. There is a second operational mode level. However, since its levels are higher than first operating mode, with enhanced risk, it is not used without ethical approval (De Wilde et al,(2007)

Monitoring of patient temperature levels during MRI diagnostic examinations is not easy, and a more practical and convenient means for monitoring patient safety during MRI diagnostic examinations is through the Specific energy Absorption Rate (SAR) parameters. RF power deposition that can lead to tissue heating can be expressed through SAR expressed in W/kg. The International Electro-technical Commission (IEC) have set limiting parameters through the software of the scanners for full body, part of the body, cranium and local diagnostic examinations in terms of SAR. For example, in the whole body scanning in MRI in the first operating SAR is not to exceed 4W/kg (De Wilde et al, 2007).

In the United Kingdom burns are the most frequently reported adverse incident associated with the use of MRI diagnostic examinations (De Wilde et al, 2007). The two common kinds of burns associated with RF in MRI are contact burns and induced current burns. Contact burns occur to patients and volunteers through poor positioning and organization of the set up in terms of the bore of the magnet and contact with metallic objects in clothes, leads of the coil, connectors of the ECG and probes that monitor oxygen, due to the significant increase in temperature in conductors exposed to RF energy radiation. Induced current burns may occur when hands and legs of the patient are placed in a manner that leads to a conductive loop pathway (MHRA Device Bulletin, 2007). Dempsey, Condon and Hadley, 2001, p.627, investigating conductive loop inductance and resonant conducting loop induction, however, suggest that the conductive loop pathway may not be responsible for induced current burns and that the real culprit may be resonant conducting loops (Dempsey, Condon & Hadley,(2001).

Causes of RF Burns in MRI
Image of an RF Burn

Three theories have emerged as to the possible heating mechanisms involved in RF burns in patients undergoing MRI examinations. These three theories are heating through electromagnetic induction, heating of a circuit in resonance through electromagnetic induction and antenna effect heating. Current flow is caused due to induced voltages in conductive media by the time-varying magnetic fields and the RF magnetic fields employed in MRI imaging. Power loss from ohmic heating can occur as a result of these circulating currents, which is called induction heating.

This electromagnetic induction heating is believed to be the most significant reason for injuries from excess heat that occurs to patients during MRI examinations. The development of a loop in the cable of the monitor gives rise to enhanced inductance in the circuit and through that inducing of larger currents and greater heating of the cable (Dempsey, Condon & Hadley, 2001).
The most serious electromagnetic heating through maximum current induction is likely to happen when a circuit is in a resonant condition.

W=1/root of LC gives the equation for the resonant condition, for exposed conducting coils to time varying magnetic fields, where L stands for the inductance of the electric circuit, C for the Capacitance, R for the resistance and W for the voltage oscillation angular frequency. Resonance is thus likely to occur at the time the inductance and capacitive impedances cancel each other out, through their being equal and opposite to each other (Dempsey, Condon & Hadley, 2001).

Monitoring cables used during MRI examinations need to be looked at as RF wire antennae, due to their sensitivity to the electric component in RF radiations. Electromagnetic waves are captured by antennae as a receiving device and energy is extracted. Electromagnetic radiation entering antennae carry with them electric charges and other forms of current. Antennae in resonance demonstrate standing wave patterns of current and voltage developed through reflections that stem from the ends of the wire that are open. Resonance in antennae develops in case the antennae are of half wavelength. In resonating antennae the electrical energy present gets collected near to a given antinode. Consequently the greatest electrical field in resonating antennae are located at the tips (Dempsey, Condon & Hadley, 2001).

Most of the RF burns reported during MRI examinations have happened when patients have been in contact with devices that monitor their physiological functions, with the thermal impact normally visible in the area that the monitoring sensor or cable was in contact with the patient's skin (Dempsey, Condon & Hadley, 2002).

Usually such burns occur because the patient is unable to sense the burning of the skin, because of sedation given for reasons of better efficiency in the imaging. For example, ECG monitoring was done to a sedated patient using Arbo infant electrodes. The duration of the scan was 30 minutes and SAR limited to 1.6W/kg. During the scanning the ECG trace was lost and on completion of the scan process, circular burns of one centimetre diameter were observed under the electrodes (Keens &Laurence, 1996).

Another example pertains to a 59-year old man and burns observed during cervical MRI. The patients arms were placed by the sides and an oximeter probe attached the fifth digit of the right hand. The hand and oximeter cable were interspaced by cloth. The oximeter cable was inspected to prevent loops. Subsequent to the examination full thickness burns were observed on the finger (Dempsey, Condon & Hadley, 2002).

Whether RF burns occur through electromagnetic induction is still undecided. Studies conducted on electromagnetic induction during MRI examinations suggest that heating that occurs through electromagnetic induction during MRI examinations is not sufficient to cause RF burns as seen in some MRI examinations, shifting the onus of RF burns to electromagnetic induction heating of a circuit in resonance and heating due to antenna effect (Dempsey, Condon & Hadley, 2002).

Prevention of RF Burns

The first preventive measure is to keep within the SAR recommendations regarding exposure of patients to RF during MRI examinations. This also includes patient evaluation prior to MRI examinations and avoidance of MRI scans in case the evaluation suggest thermal complications from MRI scans, Since there are three theoretically possible factors involved in RF burns with MRI, prevention of RF burns requires addressing these three factors(Dempsey, Condon & Hadley, 2002)
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Current guidelines concentrate on electromagnetic induction heating. These guidelines recommend that loops formed with conductive materials and the tissues of the patient are prevented from occurring. Every potential conductor must be examined to make sure that there are no frayed insulations, exposed wires or any other hazards. Such examinations in addition to the MRI scan system also include all physiological monitoring systems (Dempsey,Condon & Hadley, 2002).

Taking into consideration the possibility of antenna effect and electromagnetic induction heating of a circuit in resonance being responsible for RF burns, additional prevention measures are required to eliminate this risk. Cables should not be placed near the inner wall of the bore of the MR. Determining the antenna length at which resonance will occur and avoiding it, can mitigate the possibility of RF burns through the antenna effect.

However, since the antenna length at which resonance occurs is also influenced by the media surrounding the wires, the determination becomes complex, as the monitoring cables are to a certain extent exposed to air and for the rest in contact with the patient. Yet, it must be kept in mind that for avoidance of resonance length is necessary to reduce the risk of antenna effect and its contribution to RF burns (Dempsey, Condon & Hadley, 2002).

Conclusion

MRI has become a popular diagnostic imaging tool. It has a fairly safe record. However, RF- induced tissue heating in the human body is an issue with the RF technology used in MRI, as it can cause burns to the patient under examination. There are three theories that explain the possibility of burns in patient during MRI examinations. These are electromagnetic induction heating, electromagnetic induction heating of a circuit in resonance and heating due to antenna effect. To reduce the possibility of burns to patients during MRI examinations certain preventive measures have to be employed. These preventive measures are based on avoiding electromagnetic induction heating, electromagnetic induction heating of a circuit in resonance and heating due to antenna effect.

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