Effects of Radiofrequencies in Magnetic Resonance Imaging – a short review

Abstract
Nowadays, Magnetic Resonance Imaging is widely accepted and is becoming an increasingly useful imaging technique. For its functioning, in magnetic resonance equipments there are three main sources of electromagnetic fields: static magnetic fields, time-varying gradient fields and radiofrequencies fields. All of these fields have effects both on patients and workers. The main effect of radiofrequencies fields is heat deposition on human body, which causes tissue heating. There are international guidelines that establish occupational limits for its exposure. A good knowledge of radiofrequencies implications and its safety aspects is vital for better practices in magnetic resonance imaging.

Keywords: radiofrequencies fields, magnetic resonance imaging, effects, safety, SAR (Specific Absorption Rate).

Presentation Preference: Poster

1. INTRODUCTION
Magnetic resonance imaging (MRI) is an imaging modality widely accepted in Medicine. It uses three types of electromagnetic fields (EMFs) to produce images from human body (Coskun, 2010; Crook, 2009). Radiofrequencies fields (RF) are one type of those EMFs.

During a MRI exam, a patient is exposed to RF range of the electromagnetic radiation spectrum (10 – 400 MHz) (Riches, 2007), known as non-ionizing radiation. The major difference between this type of radiation and ionizing radiation is the fact that the latter can induce irreversible alterations on living tissues. Non-ionizing radiation only causes direct heating, via multi-photon absorption. Nowadays, RF effects on MRI are well described and studied on literature.

2. AIM
This paper has as major objective to make a survey of effects associated to RF fields used in MRI.

3. MATERIALS AND METHOD
Search databases were used to identify important and relevant experimental studies on RF fields used in MRI and systematic reviews on MRI effects and hazards published after 2005: MetaLib of Exlibris, Pubmed/Medline, Scopus and SpringerLink. A wide range of combined key-words were used, for instance: MRI, RF fields, occupational exposure limits, health effects, hazards, risks and safety.

Only published studies with a good background description and relevant conclusions were eligible. Brief communications and not published data were excluded.

In addition international reports, guidelines and directives from recognized entities, such as: Institute of Electrical and Electronics Engineers (IEEE), European Commission (EC) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) on EMFs, RF fields and MRI exposures were considered.

4. EFFECTS FROM EXPOSURE TO RF FIELDS IN MRI
RF electromagnetic waves can interact with biological tissues through a number of mechanisms (Challis, 2005; Swicord, 2010).

The major effect of acute exposure to RF fields is heat deposition, which causes tissue heating, leading to burns. In addition to interacting with human tissues, metallic materials, inside (implants and other devices) or outside (tattoos and permanent cosmetics containing iron oxides and other metal-based pigments) the patient may experience rapid and extreme heating due to applied RF (Hartwig, 2009). Sometimes it is necessary to insulate skin surface with metal-based pigments putting insulating material between patient's skin and the RF transmitter used in MRI.

Thus, health biological effects caused by RF can be grouped into two major categories (Crook, 2009; Hartwig, 2009):

- Thermal effects: caused by tissue heating by direct absorption from RF fields and induced currents.;
- Non-thermal effects: caused by a not well known process of direct magnetic field tissue interaction. As stated by ICNIRP, occurrence of non-thermal mechanisms is very low (International Commision on Non-Ionizing Radiation Protection, 2009; McRobbie, 2012).

RF are not absorbed uniformly into human body because of its tissue and volume dependencies (Gowland, 2005). Human body has the capability to dissipate excess heat. Dissipation is different from one organ to another depending on blood flow (e.g. limbs are likely to dissipate more quickly thermal energy than internal abdominal organs). Organs with low blood flow, so lack perfusion, such as eyes and testes, will take time to dissipate heat and they are particularly sensitive to heating (Coskun, 2010; Crook, 2009; Garas, 2007).

Energy dissipation can be described in terms of Specific Absorption Rate (SAR), expressed in watts(W)/kg of exposed tissue. (Crook, 2009; Hartwig, 2009). It depends on induced electric field, tissue density and its conductivity and on patient's size. In MRI, SAR levels measurement is difficult and complex to obtain because of the use of multiple parameters chosen in MRI images, which can affect energy absorption (Crook, 2009). SAR is used to calculate an

expected increase in body temperature during an average examination, where body temperature should not exceed 1ºC during examination. RF deposition is often considered to be the greatest risk for patient's safety during MRI exams.
Deposition and distribution of energy in human is extremely non-uniform and will depend on the frequency range of the incident RF waves (Table 1).

Table 1 – Division of electromagnetic frequency spectrum and correspondent absorption and deposition in different parts of human body, according to Crook et al. (Crook, 2009).

Frequency Range	Absorption and deposition in human body
100 kHz – 20 MHz	Absorption in trunk decreases quickly with decreasing frequency and considerable absorption can occur in neck and legs.
20 MHz – 300 MHz	High absorption can occur in whole body and to even higher values if partial body resonance is considered (e.g. head).
300 MHz – several GHz	Significant local and non-uniform absorption occurs.
Above 10 GHz	Absorption occurs primarily at body surface.

IEEE, ICNIRP and International Electro technical Commission (IEC), with its standard "*IEC/EN 60601-2-33 safety standard for MRI system*" established limit values to RF's occupational exposure.
IEEE and ICNIRP define their restrictions, in terms of whole-body SAR, as 0.4 W/kg with a time average of six minutes. This is one-tenth of the upper limit recommended for patients. For IEEE, SAR limits will depend on static magnetic field (SMF) strength (McRobbie, 2012).
IEC standard permits MRI workers to be exposed to the same exposure as patients: a limit of 4 W/kg (International Electrotechnical Commission, 2010) (Table 2).

Table 2 – Occupational RF limits applicable in MRI.

Institute / International Commission	SMF strength (T)	Frequency (MHz)	Whole-Body SAR (W/kg)
ICNIRP (International Commision on Non-Ionizing Radiation Protection, 2011)	Any	10-400	0.4
IEEE (The Institute of Electric and Electronics Engineers, 2005)	1T 1.5T 3T 7T	42.57 63.9 127.7 298.0	0.4
IEC (International Electrotechnical Commission, 2010)	Any	All frequencies	4

IEC has three operating modes (normal, first and second level mode), with different SAR limits well established (International Electrotechnical Commission, 2010). During an exam, MRI technologists must not allow that patients exceed the first level mode. For this reason, it is important to ask the right patients' weight and height. MRI equipments have their own software that calculates SAR limits for each patient. If the values inserted by MRI staff are too low, MRI images may have little diagnostic accuracy. If those values are too high, it can cause burns to patients, due to tissue heating.
Raising skin and body temperatures, many times patients leave MRI equipments all sweaty. This is particularly important in patients with fever because a rise on 1ºC can cause seizures.

Table 3 – SAR and temperature limits in IEC standard (International Electrotechnical Commission, 2010).

	Operating Mode		
	Normal	**First level controlled**	**Second level controlled**
Whole-body SAR (W/kg)	2	4	> 4
Rise in body temperature (ºC)	0.5	1	>1

An aspect to take into account about RF in MRI is pregnancy because of the fetus. Kikuchi et al. performed a study to evaluate body temperature elevation due to RF deposition during MRI procedures in non-pregnant and pregnant models. They conclude that safety of fetus sometimes is overestimated, because heat deposition on amniotic fluid is frequently ignored and may exceed the recommended limits (Kikuchi, 2010). This fact needs to be further examined and accurately characterized (Hand, 2010; Kikuchi, 2010; Lin, 2011). Excessive heating is a potential teratogen. For this reason, it is recommended that the duration of a MRI exam and consequently SAR may be reduced to the minimum (Coskun, 2010). Other studies have shown that the highest local heat deposition is in the mother and not in the fetus (Hand, 2006).

In MRI, equipments' SMF strengths are growing, due to better image quality. The range of RF used in those equipments is higher, increasing the risk of heat deposition on human tissues. MRI staff must be aware of that.

4. CONCLUSIONS

RF fields used in MRI can cause thermal and non-thermal effects. The predominant biological effect from RF fields is thermal, caused by potential heating of tissue by direct RF absorption and induced currents. Prevention of accidental tissue heating requires careful evaluation of the energy deposited per unit of mass in unit of time, called SAR, which is measured in W/kg of exposed tissue.

Knowing the potential effects of RF fields, workers can adopt some safety behaviors:

- Ask and insert the right weight and height for each patient;
- Avoid long time MRI examinations, just doing the strictly necessary for diagnosis;
- To prevent burns, there should be no necessary metal objects contacting the skin during the examination;
- Warn patients that during the examination may experience heat, especially if it is a long exam;
- Monitor all patients during the examination, visually and verbally. When they are unconscious use instruments for monitoring;
- Know that some MRI exams may have higher SAR values than others (e.g. abdominal and vertebral column exams when compared to limbs exams).

It is of vital importance a well knowledge of RF fields' effects for a better health and safety for both patients and workers.

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