Occupational exposure assessment of non-sinusoidal pulsed gradient magnetic fields in MRI environment

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INTRODUCTION

Exposure to time-varying EMF fields results in internal body currents and energy absorption in tissues that depend on the coupling mechanisms and frequencies involved. Relevant parameters to be assessed are: dB/dt ratio and induced current J(f). Clinical MRI systems generate gradient fields of 25÷50 mT/m and maximum slew rates of 100÷200 T/m/s within the imaging field of view. Typical frequencies are around 1 kHz but the spectral content of gradient pulses can range from around 100 Hz up to 10 kHz with non-sinusoidal patterns. In order to assess occupational exposure, specific measurements were performed and data were compared with dB/dt and J(f) reference levels derived from magnetic flux density reference levels given by the ICNIRP [1].

MATERIALS AND METHODS

Measurements and evaluations were performed on a GE Signa Excite HDx 1.5 T and a GE Signa 1.5T HD scanners, both used for diagnostic investigations. Measurements were performed using the Narda-STS ELT400 low frequency 3-axis magnetic field meter, equipped with a probe suitable for investigating pulsed signals within a frequency range of 1Hz – 400 kHz. The ELT400 provides both a measure of magnetic induction to be compared with the action values reported in Directive 2004/40/EC [2], and an analog voltage input proportional to the B-field measured by x, y, z-sensors. The time-domain x, y and z signals from the ELT400 were obtained from an instrumental chain composed by the ELT interfaced with a 4 channels oscilloscope. That allowed to separate the signal components related to the 3 axes for a subsequent waveform study and dB/dt ratio evaluation. Two different investigations were carried out. First, a preliminary study of the average induced magnetic flux density was conducted for different positions within the scanner's room during clinical activity. The second investigation was based on a detailed waveform study, dB/dt ratio evaluation and induced current calculation. As regards the first investigation, scattered low-frequency magnetic field levels were measured at 116 cm from the floor, during Spin Echo (SE) sequences (T_r=500 ms, T_e=30 ms), irrespective of slice thicknesses, signal form and specific frequency. For second investigation, measurements were performed during SE sequences within three key points: 1) bore entry (about 85 cm from the isocentre along the z-axis), 2) isocentre, 3) in the proximity of the gantry manoeuvre area. The evolution of magnetic induction for x, y and z axes was derived from voltage; the overall B trend was obtained by adding in quadrature the contribution of the three channels; dB/dt ratio calculation was performed using the sliding windows technique, setting a window size Δt equal to 0.01 s. MRI signals frequency ranged between 250 Hz and 1 kHz, and the spectrum, including harmonics, ranged from 100 Hz to 10 kHz. As a first approximation, the maximum instantaneous value of the weighted resultant equivalent dB/dt was compared to the derived peak reference level:

$$(\frac{dB}{dt})_{\lim} = 2\pi f_c B_{\lim} \qquad (1)$$

where B_{lim} is the ICNIRP reference level for occupational exposure to a magnetic field at frequency f_c expressed as an amplitude value [3, 4]. Given the spectral component of the signal, is it possible, via relation (1), to calculate in first approximation a dB/dt value. This should be compared with the values obtained from data elaboration.

Induced currents calculation were performed starting from the definition of induced current density:

$$J = \frac{dB}{dt}\frac{r}{2}\sigma = K_b \frac{dB}{dt} \qquad (2)$$

where the conversion factor K_b was set to 0.064 $Am^{-2}sT^{-1}$ in agreement with the model used by ICNIRP [4] to derive the magnetic field reference levels from the basic restrictions.

RESULTS

According to the Directive 2004/40/EC tables, action values for scattered low-frequency field levels in the frequency range 100 Hz-10 kHz can be calculated for the extreme limit of the frequency range (30.7÷250 μT). If the measured B is lower than 30.7 μT, action values are respected, regardless of signal frequency. Our preliminary measurements showed that, excluding the isocentre and some single areas located at the gantry edge, scattered B values remained below 30.7 μT. When considering the gantry edge, dB/dt were in general lower than 0.22 T/s, except in few cases corresponding to particular slice thicknesses. At the isocentre, dB/dt ratio widely exceeded the limit range for all frequencies. Within the near-gantry manoeuvre area, dB/dt ratio was well below the limit range. For gradient induced currents, the comparison between the values obtained by experimental data and the limits for current density calculated by reference to the ICNIRP Guidelines led to the following considerations: 1) Outside the gantry J(f) does not exceed the reference levels; 2) at the gantry edge (85 cm from isocentre), J(f) values, related to the same SE sequence are extremely variable, depending on the slice thickness set. In some cases J(f), related only to the fundamental frequency, may exceed ICNIRP reference levels; calculated values for superior harmonics (up to 10 kHz) did not show limits overcoming.

CONCLUSIONS

We performed measurements on two 1.5T scanners used for diagnostic investigations during standard SE sequences. Taking into account only average scattered B, the MRI environment outside the gantry can be considered safe. Instantaneous values of the weighted resultant equivalent dB/dt, and induced current J(f) for some particular slice thicknesses set during clinical investigation may exceed the ICNIRP reference level, even in positions occupied by personnel near the gantry. Further investigations are needed to define "non-safe areas" for all the clinical sequences in use.

REFERENCES

[1] ICNIRP. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz) *Health Phys.* 74 494-522, 1998

[2] Commission of the European Union. *Physical Agents (Electromagnetic Fields) Directive 2004/40/EC*, 2004

[3] S. Kännälä , T. Toivo, T. Alanko, K. Jokela . Occupational exposure measurements of static and pulsed gradient magnetic fields in the vicinity of MRI scanners. *Phys. Med. Biol* 54 2243-2257, 2009

[4] ICNIRP. Guidance on Determining Compliance of Exposure to Pulsed Fields and Complex Non-Sinusoidal Waveforms below 100 kHz with ICNIRP Guidelines *Health Physics* 84 (3): 383-387, 2003