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Brief Communication

Therapeutic Staff Exposure to Magnetic Field Pulses During TMS/rTMS Treatments

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Transcranial magnetic stimulation or repetitive transcranial magnetic stimulation (TMS/rTMS) is currently being used in treatments of the central nervous system diseases, for instance, depressive states. The principles of localized magnetic stimulation are summarized and the risk and level of occupational field exposure of the therapeutic staff is analyzed with reference to ICNIRP guidelines for pulses below 100 kHz. Measurements and analysis of the occupational exposure to magnetic fields of the staff working with TMS/rTMS are presented. Bioelectromagnetics 27:156–158, 2006. © 2005 Wiley-Liss, Inc.

Key words: occupational exposure; pulsed magnetic fields; transcranial magnetic stimulation

Although TMS is aimed at exposing patients, the nursing staff using these devices could also be exposed to magnetic pulses, eventually even to an extent surpassing the limits of occupational levels of exposure given in the new EU directive [European Parliament and the Council Directive, 2004] and the ICNIRP guideline [ICNIRP, 2003]. Concern of nursing staff working with such devices motivated the performance of measurements on the equipment currently in use at the Norrland University Hospital of Umeå, Sweden.

Non-invasive stimuli of the cortical region of conscious patients are currently accomplished through the application of localized magnetic fields. Targeted cortical areas can be selectivity exposed to magnetic pulses using different coil arrays. Among those coil configurations, the most commonly used is a pair of coils arranged in the form of the figure-8. Pulses generated can range from single pulses to trains of up to about 350 pulses per stimulation. When a transient current flows through the coil system, a strong time-varying magnetic field is locally generated in the brain, which in turn induces eddy currents that stimulate a certain neuronal volume at the cortex that in turn, through nerve transmission, stimulates functionally related subcortical regions.

While using a figure-8 coil arrangement, current flow patterns will result in two vortices that merge at a point beneath the coil intersection of the figure-8. Coils are slightly tilted in their plane as to accomplish a convergent focus of the effect at the cortical region. The field resulting in the backward direction, that is, towards the therapeutic staff is, therefore, slightly lower than the one towards the patient due to the divergent axis of the coils. This type of coil arrangement is more efficient than a single coil TMS transducer due to field symmetry considerations. Therefore, measurements on single coil transducers were not considered here.

The magnetic field transients generated by TMS equipments can be of the order of 1 Tesla with a duration of about 0.05–0.2 ms. The resulting time derivative of the field can be of the order of tens of kT/s. This transient magnetic field contributes to the depolarization of nerve cells in the brain, allowing local stimuli of the cortex of the brain reaching a maximum excitation within a blurred focal volume. The stimulus, however, has been found to extend to functionally related subcortical regions of the focused cortical center. This provides a basis for using TMS to treat the pathologic neural activity that may underlie different neuropsychiatric illnesses, particularly chronic depressive syndromes. The method has been known since the early 1950s [Penfield and Jasper, 1954], and its value as a

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therapeutic option was reviewed in 1985 by Barker et al. [1985].

The TMS/rTMS system used in this study was a MegPro unit with a magnetic coil transducer model MC-B70 (Medtronic Synectics AB, P.O. Box 265, SE-177 25 Järfälla, Sweden; http://www.synectics.se).

The coils in the transducer MC-B70 are two partially overlapped coils (~30% overlap) consisting of 10 turns of wire with a 10 mm inner and 50 mm of outer radius and a winding height of ~6 mm. Coils have been encapsulated in PVC with a minimum of 2 mm overall encapsulation and with the coils symmetrically placed in the polymeric matrix. The coils are fed from a customized current pulse generator, which is basically a regulated power supply pulsing through an electronically controlled capacitor transient discharge unit.

The measuring system used consisted of a measuring coil and a data acquisition unit. The coil was a calibrated 10 turn electrically shielded circular coil with 2.5-cm radius, and the induced voltage was registered with a Tektronix TDS 1012 two-channel digital storage oscilloscope. The E/B field rejection of the coil is better than 30 dB due to a balanced E-field shield.

Measurements were performed at three different pulse intensity settings of the equipment, intensities 6, 7, and 8, since the operating staff stated that intensity 7 is commonly and intensity 8 is rarely used; the equipment allows settings 1 through 9 and "Max." The period and the sinusoidal shape of the pulses are fixed by the manufacturer.

The dB/dt data recording measurements were performed along a vertical axis, perpendicular to the flat surface of the double coil arrangement of the Medtronic Dantec MC-B70 Magnetic Transducer. The dB/dt scans of the magnetic pulses were taken at 0.1–0.5 m distances from the transducer at ~10 cm intervals along the field symmetry axis of the transducer and away from the patient, to assess the maximum field that could affect the nursing staff. Measurements were also done along the axis of one of the coils of the MC-70B transducer, and since these values were found to be lower than those taken along the symmetry axes, only these are reported here. The results taken at various settings of the equipment gave high reproducibility while being consistent with symmetry considerations of the field; therefore, the extrapolation to higher distances is justified.

The measurements were done at environmental conditions similar to those corresponding to normal therapeutic treatments (temperature, humidity, etc.). The transducer, however, was resting in a pillow of the treatment bed without a patient. The dB/dt measuring coil was moved to search for maximal output at each measuring point.

The first finding is a confirmation of an intensity decrease of the field proportional to $1/r^3$ ($r =$ distance from the coil); see Figure 1. The pulse shape of dB/dt was recorded as shown in Figure 2.

The signal was numerically integrated to obtain the B field. The exposure to magnetic field pulse stimuli can be seen as a rather isolated excitation, in spite of the fact that they are applied in a sequence of several pulses. This allows for the cortical stimuli to accumulate charge enough to accomplish neuronal depolarization effects [Randall, 1962], that is, the pulse interval is longer than the charge decay process of the depolarization effect. Pulses are applied at a mean repetition rate of 5 pulses/s. For the pulse trains in use, we found a pulse period of about 0.3 ms and about 72 μs active pulse width, which gives an equivalent frequency of about 3.5 kHz.

ICNIRP [2003] guidelines and the newly published European Parliament and the Council Directive [2004] directive 2004/40/EC provide limitations for the level of exposure of workers to the risks arising from electromagnetic field exposure, as well as instructions for precautionary actions, such as training and information. These recommended exposure limits are aimed at avoiding excitation of the central nervous system of workers, while TMS/rTMS is aimed just at accomplishing a high level of local exposure to produce cortical excitations in patients under controlled forms. For the frequency used here, 3.5 kHz, the limit value for dB/dt is about 1 T/s (see Fig. 3 in ICNIRP [2003], guidance on determining compliance of exposure to pulsed and complex waveforms).

We could verify that the worker's exposure limits for the magnetic field pulses are transgressed at

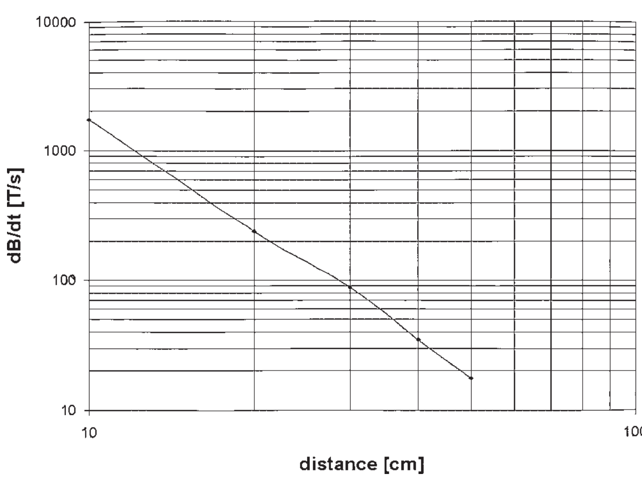

Fig. 1. Log–log diagram of peak dB/dt versus distance, showing the calculated slope of −3. The accuracy of the fitting was within ±7.5%.

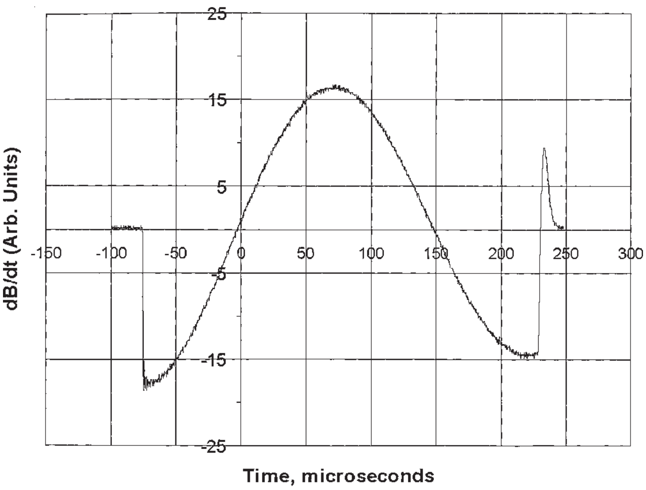

Fig. 2. Measured dB/dt at 10 cm along the central axis. Measurements were performed at the operator side of the coil and readings taken at maximal output.

distances of about 0.7 m from the surface of the transducer's coils during normal patient treatment conditions, as inferred by extrapolation from the measurements. It should be noticed that the coil handle, located in the plane of the figure-8 coils, is about 20 cm long, resulting in a short distance between the source of the field and the nurse's hand and forearm. At short distances from the coil and for all practical purposes, the TMS transducer can be seen as a single dipole, showing in cylindrical coordinates a field pattern symmetric in (θ, ψ) and decaying as $1/r^3$. The head and trunk of the operator would be at most an arm-length apart from the source, and since the basic restrictions are based on induced current in the head and the trunk for frequencies up to 10 MHz (ICNIRP and EU Directive), limiting exposures to the head and trunk is necessary.

Further studies, especially of different designs of TMS devices, should be made to bring deeper insight in the issue of whether the settled limits in terms of induced current density on the staff also are transgressed. Until those studies are pursued, it is suggested that the clinical staff should not work at distances closer to 0.7 m from the transducer to avoid risks of overexposure to magnetic pulses, a recommendation that is valid for both single coil and figure-8 transducers, as due to basic field symmetry considerations.

The Dantec MC-B70 equipment could be used with a mechanical arm holding the transducer in the right position for the patient. This device should always be used in order to avoid exposures that arise while handholding the probe during treatment sessions. If similar devices are available for other TMS/rTMS products, they should be used instead of handholding transducers during treatments, thus allowing the nursing staff to step away from the zone of high level of exposure and stand at least 0.7 m apart from the transducer and its cable.

In conclusion, staff working with patient treatments with TMS/rTMS can become exposed to magnetic field levels exceeding both EU directive and ICNIRP guidelines; therefore, it is recommended that procedures are developed to avoid unnecessary exposure of nursing staff along with instructions as recommended in the referred documents.

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