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Letter to the Editor

Minimal heating of aneurysm clips during repetitive transcranial magnetic stimulation

1. Introduction

Repetitive transcranial magnetic stimulation (rTMS) is a noninvasive neuromodulatory technique whose use in clinical practice has increased steadily since in 2008 the Food and Drug administration (FDA) approved the Neuronetics NeuroStar System for treatment of certain patients with medication-resistant major depression. Although generally well-tolerated, rTMS safety warrants special consideration in certain patient populations, such as those with prior cranial surgery and metallic implants where a plausible risk of heating or displacement of the metallic parts should be considered before treatment (Rossi et al., 2009, 2011; Rotenberg et al., 2007; Rotenberg and Pascual-Leone, 2009). Among these are patients who have undergone subarachnoid aneurysm clip ligation. As no clinical safety data are available to assess the risk to health of rTMS in patients with intracranial aneurysm clips, we performed the present experiment aimed to measure whether an aneurysm clip composed of the most common cobalt–chromium–nickel alloy (Co–Cr–Ni) may be heated by rTMS.

2. Methods

We used a NeuroStar magnetic stimulator and compatible treatment coil (NeuroStar TMS Therapy® System, Neuronetics Inc, PA, USA) to deliver a typical rTMS protocol (10 Hz, 110% of motor threshold under 1.45 standard motor threshold, 100 trains, 4 s on, 6 s off, total 4000 pulses). For the intensity of rTMS, we limited testing to 110% with magnetic fields equal to about 2.22 ± 0.3 T (mean ± SD), assuming that lower intensities would be associated with lower amplitude eddy currents and less heating.

During a simulated rTMS session, we recorded surface temperature from representative Phynox (Co–Cr–Ni alloy) clips FE640K, FE650K and FE660K (Yasargil® Aneurysm Clip System, Aesculap Inc, PA, USA) Fig 1; frequently used for ligation of subarachnoid aneurysms (Otawara et al., 2009). The strength of magnetic field at each distance from the coil was measured by a gaussmeter (GM08, Hirst Magnetic Instruments Ltd, UK). Throughout the rTMS session, a thermocouple probe (HH309A, Omega Engineering Inc, USA) was in contact with the aneurysm clip directly and two additional thermocouple probes recorded the temperature of stimulating coil surface and also the ambient (room) temperature for subsequent analysis. Temperature was measured with a sampling rate of 0.5 Hz while the aneurysm clip position was systematically manipulated as follows:

2.1. Experiment 1: Contribution of distance from rTMS coil to aneurysm clip heating

A common aneurysm clip (FE650K: 9 mm), Fig 1, was positioned 1, 5 or 10 cm in the *xy*-plane from the center of the stimulating coil surface per individual stimulated rTMS trial. Thus the temperature changes were measured at varying distances from the coil center.

2.2. Experiment 2: Contribution of aneurysm clip size to its heating

Temperature changes for two aneurysm clips, the largest and smallest in our sample, Phynox FE640K (6 mm) and FE660K (12 mm) were measured with the clips positioned in the *xy*-plane at a distance of maximal heating from the coil center using the same rTMS parameters as in Experiment 1.

2.3. Experiment 3: Contribution of aneurysm clip orientation to its heating

Based on results of the above measurement, the aneurysm clip exhibiting maximal heating in the *xy*-plane was then stimulated to evaluate temperature changes in *yz*- and *xz*-planes relative to the coil center.

3. Results

The coil surface temperature gradually increased during the sessions of 10 Hz rTMS, reaching peak temperature, an increase of 6.63 °C from baseline, after approximately 3000 s of stimulation in particular session (Fig 2A). The ambient room temperature was nearly unchanged (increased 0.3 ± 0.2 °C) per rTMS session. The maximal magnetic field measured at 0, 1, 5 and 10 cm distance from the stimulation coil per 10 pulses and averaged over 3 trials was 2.08 ± 0.18, 2.22 ± 0.30, 1.37 ± 0.06, and 0.38 ± 0.05 gauss, respectively.

3.1. Temperature changes during rTMS as a function of distance

Maximal heating (1.9 °C above baseline) occurred with the aneurysm clip FE650K positioned closest (1 cm) to the coil surface as observed in Fig 2A. With increasing distance from the coil surface, the peak increase in aneurysm clip temperature was 0.5 °C and 0.3 °C, at 5 cm and 10 cm distance respectively.

3.2. Temperature changes during rTMS as a function of clip-size

Aneurysm clips are available in various sizes either slightly shorter or longer than the tested model. Since a separation of 1 cm from the coil surface resulted in maximal heating with

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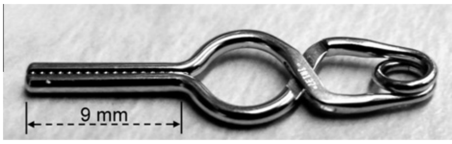

Fig. 1. Photograph of a representative aneurysm clip FE650K.

FE650K, two more clips were stimulated at a distance of 1 cm in the *xy*-plane relative to the coil center to test for size-based heating effects. The peak increase in FE640K aneurysm clip temperature was 1.1 °C whereas it was about 2.56 °C in case of FE660K (Fig 2B). Thus FE660K had maximum change in temperature when positioned 1 cm away from the coil surface in the *xy*-plane with respect to the coil center.

3.3. Temperature changes during rTMS as a function of orientation of clip

As circumstances in vivo may vary, orientation of the clip in relation to the coil is a relevant factor. Therefore, using the same TMS protocol we then tested FE660K at a separation of 1 cm in two other planes with respect to the center of TMS coil. By orienting the clip in *yz*-plane, a maximal heating (0.68 °C above baseline) occurred as compared to a change of 1.63 °C in *xz*-plane of the coil (Fig 2C).

4. Discussion

We assessed the distance-, size- and orientation-based heating effects of a common clinical rTMS protocol on frequently used aneurysm clips.

We found that aneurysm clips of Phynox, a cobalt–chromium–nickel alloy, are minimally heated during a conventional rTMS protocol delivered with an FDA-approved TMS device, even when positioned at distances (1 cm from coil surface) that are unrealistic to encounter in clinical practice. However, it is worth remembering that, at least theoretically, the circumstances in the real brain may be different and current shunting could modify the findings. Therefore, although the results are reassuring they cannot be taken to completely rule out risks. As previously (Rotenberg et al., 2007) we encourage investigators to perform *ex vivo* studies of the effects of fluctuating magnetic fields on metallic objects, which may be encountered with the intracranial space in patients undergoing rTMS in order to minimize risks.

5. Disclosure

Dr. Pascual-Leone serves on the scientific advisory board of Starlab, Neuronix, Nexstim, and Neosync. Drs. Pascual-Leone and Rotenberg are listed as inventors on patents (APL) and patent applications (APL and AR) on the integration of TMS with EEG and MRI.

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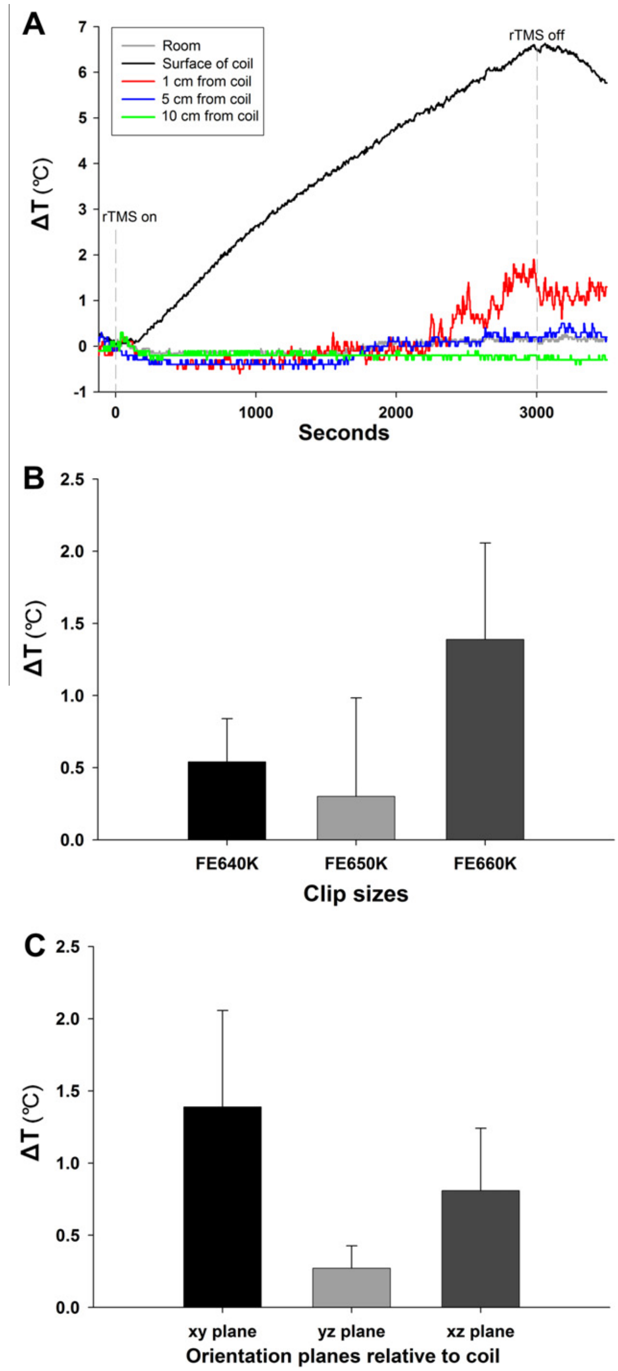

Fig. 2. (A) Temperature changes during rTMS as a function of distance from the coil. Aneurysm clip FE650K was positioned 1 cm, 5 cm and 10 cm away from the magnetic coil surface. Mock stimulation was applied for 3000 s. The graph plots the change in temperature from baseline. Note: whereas the maximal rTMS coil temperature increase was 6.63 °C from baseline, the aneurysm clip maximal temperature increase was 1.9 °C when closest to the rTMS coil surface. (B) Temperature changes during rTMS as a function of clip-size. Three aneurysm clips viz. FE640K, FE650K and FE660K of varying sizes were positioned at 1 cm from the coil surface. The graph plots the mean and standard deviation during the mock stimulation of 3000 s. Note: FE660K had the maximum temperature increase of 2.56 °C from baseline. (C) Temperature changes during rTMS as a function of orientation of clip. Aneurysm clip FE660K was positioned at 1 cm in 3 orientations viz. *xy*-, *yz*- and *xz*-planes relative to the coil surface. The graph plots the mean and standard deviation during the mock stimulation of 3000 s. Note: FE660K oriented in the *xy*-plane had the maximum temperature increase of 2.56 °C from baseline.

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