Threshold for Peripheral Nerve Stimulation with Ultra-Fast Gradients

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Introduction

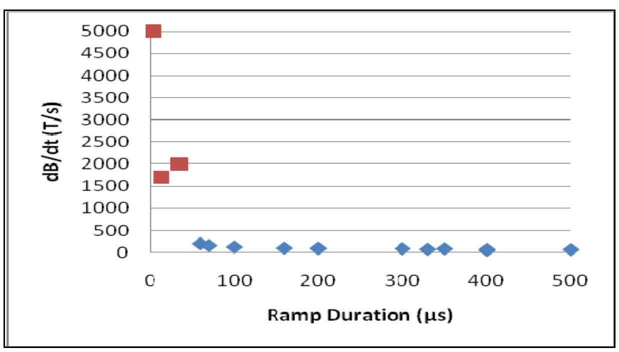
In clinical MRI scanners, dB/dt is limited to typically below 50 T/s (for a ramp duration of 0.2 ms), due to unpleasant peripheral nerve stimulation ("PNS") caused by electric fields induced in the body [1]. Prior clinical trials involving magnetic gradients, with rise- and fall-times as short as 50 µs (with dB/dt rates as high as 400 T/s [2]), and slew rates as high as 400 T/m/s [3], have suggested that the dB/dt threshold for stimulation PNS asymptotically increases with shorter transition times. These predictions have not hitherto been examined experimentally for rise-times below 50 µs. We therefore conducted an experimental study of PNS with magnetic gradients in this ultra-fast regime (i.e., rise-times of just a few microseconds).

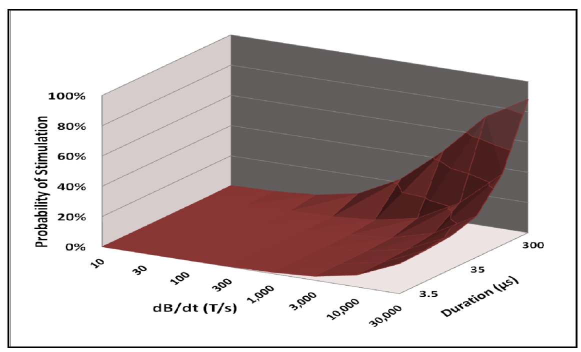
Methods

The right hands of twenty-six volunteers (with age ranges from 18 to 67) were exposed to series of bipolar and unipolar magnetic gradient pulses with ramp times as short as 3.5 µs and a maximum dB/dt of 13,000 T/s. The pulse trains were created using proprietary pulse-power technologies (adapted from plasma physics experiments [3]) with a coil of inductance 110 µH, to which a maximum voltage of 8200 V was applied. Sham pulses (i.e., dB/dt = 0) were employed to discriminate against placebo effects. Data were analyzed using a logistic regression model relating probability of PNS to the age, sex, dB/dt, polarity (unipolar and bipolar) and transition-times.

Results and Discussion

Our study shows that in addition to the expected dependencies (on ramp time and gradient strength) the likelihood of nerve stimulation significantly depended on age (P<0.005) and to a lesser extent on polarity (P<0.13). At ramp times of 3.5 µs, our model (see Figure) predicted that 5% of the general population will exhibit PNS at dB/dt levels above 6,000 T/s for unipolar pulses, and at 3,000 T/s for bipolar pulses. Similarly at 3.5 µs 50% of the general population (with an average age of 40) will exhibit PNS at dB/dt levels of 128,000 T/s for unipolar pulses, and 68,000 T/s for bipolar pulses. These threshold levels are significantly higher than would be extrapolated from prior studies that were conducted with longer transition times [1]. The model predicts that at the "5% likelihood-for-stimulation-threshold" for subjects younger than 21-years-of-age is three times lower than the same threshold for subjects older than 50-years-of-age. Gradient pulses in this study were applied within 10-cm, thus maximum applied slew rate was on the order of 130,000-T/m/s.





Left: data collected from this study for 5% probability of PNS (in red) compared to prior published results for PNS thresholds (in blue) abstracted from Schaefer *et al* [5], based on prior publications [6-8]. Right: modeled probability for PNS (unipolar pulses, avg. age 40.)

Conclusion

Experimental studies of PNS demonstrate that at ultra-short rise- and fall-times, very high slew rates (i.e., 130,000 T/m/s) can be applied without causing peripheral nerve stimulation. Younger subjects have lower dB/dt stimulation thresholds than older patients.

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