Increased PNS thresholds using a Novel Composite Gradient System

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Introduction

Currently improvements in gradient performance are limited by peripheral nerve stimulation (PNS) standards apposed to hardware limitations. PNS induced by MRI gradients is still not fully understood[1]. To the credit of the MR community PNS safety standards conservatively limit gradient performance[2]. As PNS is better understood with respect to MRI it is possible that these limits can be modified under certain conditions to increase gradient performance allowing increased image resolution, acquisition speed, and signal to noise ratio as well as artifact reduction[3]. The purpose of this study was to test PNS levels associated with a novel gradient system that allows an insert gradient to be used simultaneously with the standard whole-body gradient system. The effects of such a composite gradient system on PNS levels have not previously been examined or reported.

Vol	Age	Weight (lbs)	Height	Gender
1	58	190	6'1"	m
2	28	135	5'8"	f
3	27	120	5'9"	f
4	59	185	6'	m
5	63	185	6'2"	m

Table 1: Volunteer details

Methods

With IRB approval and informed consent 5 volunteers underwent nerve threshold testing using whole body gradients (40mT/m X + Y gradients) and a head/neck gradient insert. See Table 1 for volunteer details. Tests were performed in a Siemens 3T TIM Trio scanner (Siemens Medical, Erlangen Germany) equipped with TQ body gradients and a gradient insert designed for neck and head imaging[4]. The system was augmented with three additional gradient amplifiers and master/slave configured computers capable of controlling extra gradient channels. A separate pulse sequence was used to control identical waveforms on each gradient set. The master computer controlled the standard body gradients and triggered the slave computer to run the insert synchronously. The output of each axis was limited to 34 mT/m for this preliminary study. At this limit X and Y combined yields a maximum 48 mT/m in single gradient mode and 96 mT/m in composite mode, over the region where the insert and body gradients are superimposed.

Subjects were instructed about muscle and sensory PNS to help them report it when sensed. Volunteers were positioned with their head fully in the gradient insert centered radially with shoulders touching the edge of the insert. The insert was aligned with the magnet for all tests such that the region of uniformity (ROU) for the insert was centered within that of the whole-body gradients (as would be standard for head imaging with this system). After each session, assessment of nerve stimulation location and sensation (twitch, poke) were recorded.

Three gradient configurations were measured in random order: 1) body gradients only, 2) insert gradients only, 3) both systems operating synchronously (composite mode) with equal amplitude. Subjects were not informed of the order; however, differences in the acoustic noise did provide feedback as to what the configuration was. The pulse sequence consisted of 64 1 msec trapezoid pulses with slew time of 400 µsec (see Fig 1), which was repeated 10 times with a TR of 1sec. Transverse (X,Y) gradients were run simultaneously starting with an amplitude of 5mT/m for X and Y gradients (7 mT/m vector sum). If no stimulation was felt the amplitude was increased by 5mT/m with the same rise time until stimulation occurred or maximum gradient strength was reached without stimulation. After reported stimulation, the gradient values were reduced by 4 mT/m and stepped by 1 mT/m to refine the threshold of PNS onset.

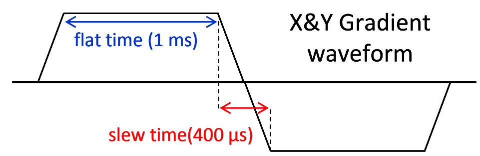

Figure 1: PNS pulse sequence

Vol	Body mT/m	Composite mT/m	Insert mT/m
1	27	59	no
2	30	61	no
3	30	44	no
4	21	44	no
5	31	51	41

Table 2: Stimulation thresholds for 400 µsec slew time. Values are rounded to nearest integer and are the vector sum of X and Y gradients.

Results

All volunteers felt PNS with at least 2 gradient configurations. Only one volunteer was stimulated by the insert gradient only, consistent with results reported previously in studies using that coil[5]. Most importantly, in all cases the PNS threshold for composite gradients was higher than for the body gradients only. The units in the table are in mT/m (vector sum of X and Y) at 400µs slew time. Figure 2 shows the thresholds in terms of slew-rate, comparing whole body and composite gradient PNS thresholds.

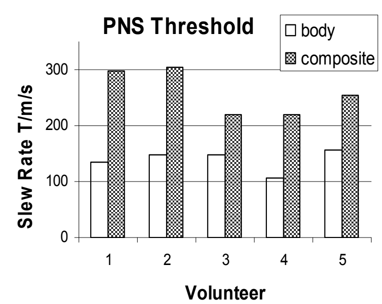

Figure 2: Comparison of body and composite PNS slew rate thresholds.

Discussion and Conclusions

Zhang et. al. have shown that PNS thresholds generally increase with decreasing gradient size[5]. Our original hypothesis was that by combining the gradient fields of 2 different gradient sets, we would observe PNS thresholds somewhere between those of the component coils. In fact, for composite mode compared to body mode only we observed an increase in the mean threshold of a factor of 1.8 +/- 0.1, showing this assumption to be valid. This is most likely due to smaller field excursions outside the ROU for this composite system than that of the body gradients alone. These results suggest that this configuration may allow increased gradient performance while decreasing PNS relative to whole body gradients alone. Furthermore, it is possible that a different combination of gradient strengths could allow for an even larger increase in the stimulation threshold. It should be noted that Z gradients were not tested for stimulation in this study. Transverse gradients are typically responsible for the lowest nerve stimulation thresholds[6] and are, therefore, the limiting gradients for PNS safety.

References

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