PNS Safety of the Composite Gradient System

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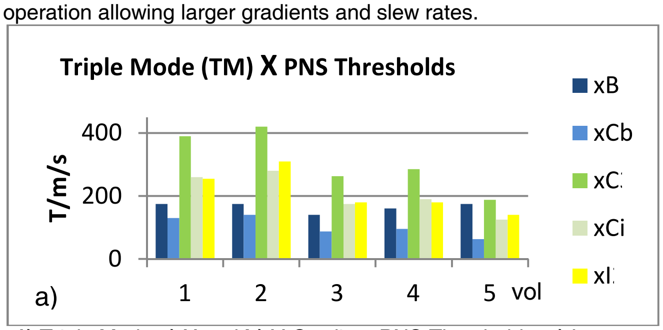
Target Audience: Anyone interested in increased gradient performance without increased peripheral nerve stimulation (PNS).
Purpose: Establish PNS limits for simultaneous operation of a 3 axis head/neck gradient insert and standard whole body gradient system.
Introduction: This work presents the results from PNS comparison studies using 1) body gradients only, 2) insert head/neck gradients only and 3) simultaneous operation of body and insert gradients (composite mode[1]). We previously reported PNS measures for a 2 axis head/neck insert operating together with the standard gradient system[2] but only tested X and Y axes operating together.
Methods: With IRB approval and informed consent, 10 volunteers underwent nerve stimulation testing using our composite gradient system. Tests were performed in a Siemens 3T TIM Trio MRI scanner (Siemens Medical, Erlangen Germany) equipped with TQ body gradients and a gradient insert designed for neck and head imaging[3]. The system has three extra gradient amplifiers and master/slave configured computers capable of controlling extra gradient channels. The master computer controls the standard body gradients and triggers the slave computer to run the insert synchronously with the standard gradients, creating an imaging gradient equal to the sum of the two component gradient systems. Volunteers were positioned with their head centered radially and completely inside the insert gradient with shoulders touching the edge of the insert. The linear region of the insert was aligned with the isocenter of the whole-body gradients for all tests (as would be standard for head imaging with this system). The three gradient configurations were measured in random order. The pulse sequence consisted of 64 1ms trapezoid pulses with slew time of 400 µsec (from maximum positive to maximum negative amplitude), which was repeated 10 times with a TR of 1s. After each scan, assessment of nerve stimulation location and sensation (twitch, poke) were recorded. ***Double Mode (DM):*** Five volunteers were tested with the insert operating equal to the body gradient strength. For this study, a single volunteer repeated the Y stimulation measurement 7 times to estimate error. ***Triple Mode (TM):*** Five volunteers were tested with the insert operating at double the body gradient strength creating an effective gradient triple that of the standard body gradient field. Individual components of the TM composite field were separated into body and insert contributions (1/3 and 2/3 respectively). The TM composite X gradient field (xC) equals the x-contribution from the body gradient (xCb) plus the x-contribution from the insert gradient (xCi). Body and insert only x-gradients are referred to as xB and xI, respectively. Similar relations apply for the Y gradient.
Results: Volunteers typically reported torso PNS induced by body only operation and head PNS by insert only operation.
Double Mode: No volunteer stimulated during insert only operation. All composite mode stimulation thresholds were above those measured for the body only operation. For a single volunteer, the slew rate threshold reproducibility error estimate was 99.4±5.6 T/m/s. ***Triple Mode:*** Some of the volunteers were stimulated when the insert was set to double body gradient strength. Stimulation thresholds for the composite mode were consistently higher than either the insert only or body only configurations. Table 1 lists the number of volunteers stimulated with each configuration.

Table 1	X(DM)	X(TM)	Y(DM)	Y(TM)	Z(DM)	Z(TM)	XYZ(DM)	XYZ(TM)
Body	0	2	5	5	4	2	5	5
Insert	0	5	0	1	0	2	0	5
Composite	2	5	5	5	1	3	5	5

Discussion and Conclusions: The composite mode stimulated when either the body gradient or insert gradient components reached the same stimulation thresholds that they achieved in their individual modes. Figure 1 compares composite field components with body only and insert only mode thresholds. In Fig 1a), the stimulation thresholds for the insert only gradient (xI) were essentially the same magnitude as the insert component of the composite gradient (xCi), indicating an insert gradient dominant stimulation for X composite PNS. Stimulation locations during X Gradient experiments occurred in the head, further indicating insert gradient dominant stimulation. In Fig 1b), the stimulation thresholds for the body only gradient (yB) were essentially the same magnitude as the body component of the composite gradient (yCb), indicating a body gradient dominant stimulation for Y composite PNS. Both Y Gradient experiments resulted in torso stimulation, further indicating body coil dominant stimulation. These results suggest that body and insert gradient thresholds are independent of each other, allowing for increased combined gradient field strength and slew rates in composite mode until either constituent threshold is reached. These results show a definite safety advantage for composite gradient mode operation allowing larger gradients and slew rates.



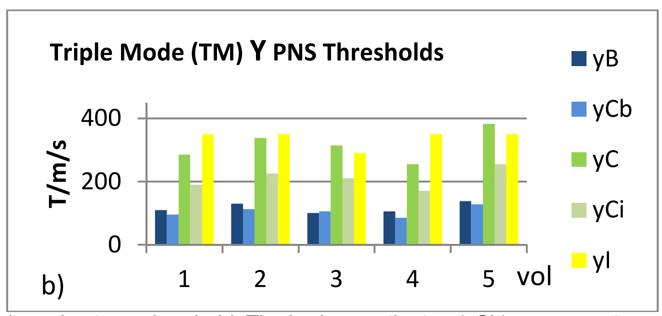


Figure 1) Triple Mode **a)** X and **b)** Y Gradient PNS Thresholds. **a)** Insert gradient dominant threshold. The body contribution (xCb) to composite operation did not reach the PNS threshold for the body only mode (xB), while the insert contribution (xCi) is close to the insert only mode (xI) thresholds for all volunteers. xC is the composite mode theshold. (xCb+xCi=xC, xCb*2=xI) **b)** Body gradient dominant threshold. Insert only thresholds (yI) are much higher than the body gradient portion (yCi) of the composite and do not seem to be the limiting element for composite thesholds. Body gradient portion thresholds (yCb) more nearly match the body only thresholds (yB). yC is the composite mode theshold(yCb+yCi=yC, yCb*2=yI)

References
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