# Observed issues in predicting peripheral nerve stimulation caused by gradient switching

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**Abstract**
The purpose of this work is to determine the average PNS threshold level, primarily in order to comply with the second edition of the IEC 60601-2-33 safety standard [1]. Experiments were performed with the latest generation gradient hardware (88 mT/m, 240 T/m/s). The conclusion is that even when the onset of sensation threshold is known for a volunteer, for a particular scan the accuracy of predicting PNS is estimated to be 50-150%. Nevertheless, the effective usage of a model and the predetermined PNS threshold levels has increased the maximum allowed gradient output on average with 20% as compared with the default values given in the IEC standard.

**Methods**
Experiments have been performed on a clinical MRI scanner (Philips Medical Systems) with a gradient amplitude of up to 88 mT/m and a slew rate of up to 240 T/m/s (values on each Cartesian axes). The experiments were set up according to the guidelines as set forth in the IEC standard (applying all gradient units individually and in different combinations and stepping the gradient strength up until the onset of stimulation is reached). The experiment was conducted in two phases. In the first phase 33 volunteers were subjected to a series of 35 EPI-like waveforms with identical direction and varying slope duration, flat top duration and number of pulses. The data set was matched to obtain optimal discrimination of the nerve stimulation model parameters. The volunteer was positioned at the worst-case anatomical location, which is the groin being in the isocenter. This experiment was completed within 15 minutes for each volunteer. A published model [2] has been used to analyze our data.
The determination of the weight factors was conducted in the second phase, in which each of the 5 volunteers were positioned at 5 different anatomical positions (nose, heart, umbilicus, groin and knee), and subsequently subjected to 13 waveforms with permutation in directions. This experiment took an hour per volunteer.

**Results**
The analysis of the first phase - which is essentially one dimensional, and models the nerve behavior only - shows a very good match between model and observed results, namely 3% average deviation of observed personal threshold. The highest threshold observed was 1.75 times the lowest threshold. Our experiments also show a strong correlation with gender.
In the second phase we observed a 0-30% variation of personal thresholds for varying directions, and 50-100% for variation in anatomical positions. Most notably the knee position showed significantly higher thresholds.
The effective usage of this model, the derived parameters and PNS threshold levels has increased the maximum allowed gradient output significantly as compared with the default values given in the IEC standard.

**Discussion**
Our findings are in agreement with a recent publication of Faber *et al* [3], namely the dependency on anatomical position and gradient orientation, and correlation with the gender.
In practice the applied limits are worst case, ensuring safe operation. Incorporating knowledge of certain examination characteristics (e.g. patient position, gender, type of scan, the patient's individual threshold) can be very advantageous in order to enhance clinical performance. Based on the results we expect that under certain conditions the allowed gradient output can be increased by a factor of two.
We recognize that for a general MRI pulse sequence the concept of gradient orientation does not exist. In order to improve the reliability of prediction of the occurrence of PNS significantly, it is imperative that a good understanding of the relation between the time- and position dependent gradient fields for a general 3-axes waveform and the occurrence of peripheral nerve stimulation is needed. Simulations such as [4] can help to gain insight to develop such a model. When this insight becomes available, occurrence of PNS can be prevented more reliably whilst optimally exploiting today's high performance gradient systems.

**References:**
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