Dynamic Slew Rate Pulse (DSRP) for PNS alleviation

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Synopsis:

In this study, a new gradient pulse, Dynamic Slew Rate Pulse (DSRP), is designed to reduce peripheral nerve stimulation (PNS). Compared with traditional trapezoid pulse, DSRP's pulse width is much smaller when dB/dt limitation is dominant.

Introduction

Electric fields induced by changing magnetic fields can cause peripheral nerve stimulation (PNS). FDA and MR manufacturers set limits on the maximum change rate of the magnetic fields, known as dB/dt limit, to avoid painful stimulation. Due to such patient safety restrictions, improved hardware capabilities are not always translated to best pulse sequence performance (in terms of minimum TE, echo-spacing, and minimum TR). It has become more and more important to design fast pulse sequences that produce less PNS effects. One method based on trapezoid pulse was present to optimize minimize PNS effects in EPI [1].

DSRP that we introduce here is a basic gradient waveform. It can be used in any pulse sequence to alleviate dB/dt limitation. DSRP is generated according to target PNS curve. The PNS curve of traditional trapezoid pulse is shown in Fig.1 and maximal absolute PNS is reached only at one point. The PNS curve of DSRP is shown in Fig.2 and absolute PNS keeps in maximal value for one period.

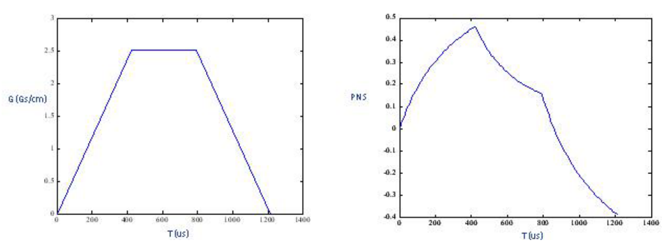

Fig 1. Left: one example of traditional trapezoid pulse whose pulse width is about 1200us; Right: the PNS caused by trapezoid pulse. Note: a) PNS curve is calculated with convolution model defined in IEC-60601-2-33(2002) in section 51.102. b) Maximal Slew Rate is 200 T/m/s

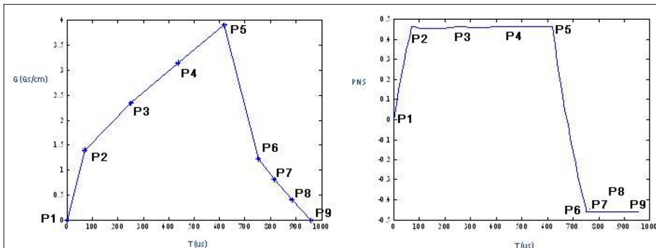

Fig 2. Left: one example of DSRP with 9 corner points whose pulse width is only 960us with same area as trapezoid pulse shown in Fig 1; Right: the PNS caused by DSRP. Note: a) PNS curve is calculated with convolution model defined in IEC-60601-2-33(2002) in section 51.102. b) Refer to Table 1 to get Hardware specification.

Methods

The steps to produce DSRP are presented below:

1. Define target PNS curve that meets below requirements
   a. Reach maximal positive PNS as quickly as possible in ramp period (P1 to P2).
   b. Keep PNS in maximal positive value as long as possible in ramp period (P2 to P5)
   c. Reach minimal negative PNS as quickly as possible in drop period (P5 to P6)
   d. Keep PNS in minimal negative value as long as possible in drop period (P6 to P9)
2. Calculate time and amplitude of P2 with Maximal Slew Rate and target PNS using convolution model.
3. Calculate amplitude of P3, P4 and P5 with given times, target PNS and convolution model.
4. Calculate time and amplitude of P6 with Maximal Slew Rate and target PNS using convolution model.
5. Calculate time of P7, P8 and P9 with given amplitude and target PNS using convolution model.
6. Calculate area based on P1 to P9. If it does not equal to target area, change the time for P3, P4, P5 and repeat step 3 to 5 until calculated area equals to target area.

Here, in order to make description simple, we suppose that target area is bigger enough not to change P2.

Maximal amplitude	5	Gs/cm
Maximal Slew Rate	200	T/m/s
rheobase	23.7	T/s
chronaxie	370	us
Effective gradient coil length	34.4	cm

Table 1: Hardware specifications

Results

DSRP is applied in 3D Fast GRE. Hardware specifications are gotten from GE scanner and shown in Table 1. Under 1st control mode, the minimal TR is 6.2ms and minimal TE is 2.7ms without DSRP. After applied DSRP, minimal TR is shorten to 4.9ms and TE to 2.05ms. Fig 3 shows comparison of pulse sequences under two conditions. The minimal TR is reduced by 21% and minimal TE is reduced by 24%.

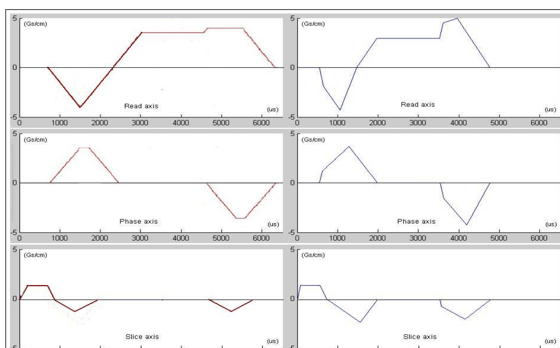

Fig 3. Left image (with Trapezoid pulses): Actual Slew Rate is only 117T/m/s due to dB/dt limitation. Minimal TR=6.2ms and Minimal TE=2.7ms; Right image (with DSRP pulses): Minimal TR=4.9ms and Minimal TE=2.04ms.

Discussion

Some examples of DSRP have been presented to alleviate dB/dt limitation and get good benefits. All the results here are gotten by simulation in Matlab. With different target PNS curves, DSRP can have variable types. Even target PNS curve is same, DSRP shape changes with different area, maximal gradient amplitude and slew rate. It leads much more complex pulse sequence generation compared with traditional trapezoid pulse. In further work, we will realize it in actual scanner to evaluate its performance.

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References

1. Peripheral-Nerve-Stimulation-Optimized Gradient Waveform Design Beibei Zhang‘,*, Graeme McKinnon3, Brian R ut t ’ Proc. Intl. Soc. Mag. Reson. Med. 10 (2002).