A Conservative Method for Ensuring Safety within Transmit Arrays

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INTRODUCTION

With transmit RF arrays it is possible to vary the RF magnetic (B_1) field distribution within a given subject to achieve any number of goals with methods such as RF shimming (1) and transmit SENSE (2). With some methods, such as transmit SENSE, the magnetic field distribution is varied during the RF pulse. This makes determination of local SAR levels very difficult because the SAR pattern will change through time.

Although the safety of a single RF coil can be determined based on the expected B_1 field distribution of that coil, with a transmit array the field distributions that will be used in an experiment may not be known before the beginning of an experiment. This makes it difficult to accurately assess local SAR levels for specific experiments in a timely manner.

Here we propose a method for ensuring the safety of the transmit array based on finding the worst-case ratio of local SAR to average SAR and using that ratio along with the real-time measured input power to the array to ensure limits on maximum local SAR are not exceeded.

METHOD

We modeled the human head in a 16-element transmit array as described previously (3) and shown in Figure 1. We calculated the electromagnetic field distribution as produced by each element separately when driven with current sources and used the resulting field distributions and the principle of superposition in a home-built optimization routine. Rather than perform optimizations on the B_1 field distribtions as in previous work (3), we used routines to determine the maximum and minimum achievable ratio of local SAR to head-average SAR for comparison to both IEC and FDA limits (4, 5). This requires evaluating the maximum local SAR in any 1-gram region (SAR_{1g}) for comparison to FDA limits, and evaluating the maximum local SAR in any 10-gram region (SAR_{10g}) for comparison to IEC limits. For comparison, we also optimized to minimize the ratio between maximum local SAR and average SAR, and we also present the ratio between maximum local SAR and average SAR for a standard drive with all element currents being equal in magnitude and having phase proportional to the azimuthal angle of position. All calculations were performed for 300 MHz.

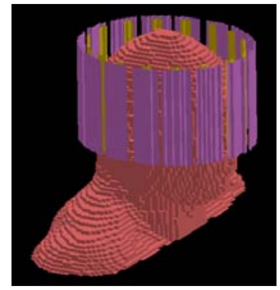

Figure 1 Model geometry. Array based on designs at University of Minnesota (7).

RESULTS

Table 1 gives the maximum achievable ratio of maximum local SAR (SAR_{1g} or SAR_{10g}) to head-average SAR (SAR_{ave}) for different drives including a standard quadrature drive, and drives which maximize or minimize the ratio. The ratios of maximum local SAR to SAR_{ave} in regulatory limits are also given.

Table 1 Ratio of maximum local SAR (SAR_{1g} or SAR_{10g}) to head-average SAR (SAR_{ave}) for different drives including a standard quadrature drive, and drives which maximize or minimize the ratio. The ratio of maximum local SAR to SAR_{ave} in regulatory limits are also given.

	SAR_{1g}/SAR_{ave}	SAR_{10g}/SAR_{ave}
Standard Drive	7.40	4.45
Drive Maximizing Ratio	187.39	57.59
Drive Minimizing Ratio	4.32	3.41
Ratio in FDA Limits	2.67	-
Ratio in IEC Limits	-	3.125

DISCUSSION

Because the head-average SAR can be estimated in real time during an experiment using the input power to an array and the mass of the exposed portion of the body, numbers like those in Table 1 where the ratio of maximum local SAR to average SAR has been maximized can be used to ensure that limits on local SAR are not exceeded, even when the SAR distribution throughout a given pulse or experiment may not be known. For example, in the most conservative approach whole-head average SAR levels in experiment would not be allowed to exceed a value equal to the whole-head average SAR level in the regulatory limits divided by the maximum achievable ratio from Table 1. The numbers shown in Table 1 also indicate that the regulatory limits on local SAR will always be exceeded before those on head average SAR are exceeded when imaging with a transmit array. This is in agreement with a previous study for head and body volume coils (6).

Because the ratio of maximum local SAR to average SAR in the head has a very large range, utilization of the method proposed may be conservative to the point of being very restrictive. It is also important to note that in our preliminary experience, the ratio tends to be higher for RF-shimmed field distributions than for the standard drive shown in Table 1. This emphasizes the need for more accurate methods of determining local SAR levels for transmit arrays in practice.

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