Spurious Proton Signal from Phased Array Coil Materials- How Much Proton Signal is Too Much?

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Introduction

In MR Imaging the properties of the materials used for building Phased Array Coils are very important. All components of the Phased Array Coil must be inspected for its material properties. Primary concern must be for the static magnetic properties which are characterized through magnetic susceptibility [1]. Second concern (but not less important) is the following Hydrogen nuclei information: quantity, volume spin density, spin-lattice decay time T_1 and spin-spin decay time T_2 and the chemical shift (desirably). A receive RF coils contains material like Kapton™ tape, Delrin™ rods, Polycarbonate, Nylon etc., which do contain a certain amount of proton signal. The ideal situation would be to eliminate completely all Hydrogen from all building components. However, it could be costly and sometimes unnecessary if the amount and relaxation times T_1 and T_2 are correlated with existing gradient slew rates, RF pulse width and the very matter we intend to image – living organisms.

There are three primary types of contrasts in MRI imaging: spin density contrast, T_1 (spin-lattice interaction) contrast and T_2 (spin-spin interaction) contrast. Usually, the imaged tissue has a small variation in spin density but quite different T_1 values. An effective method to obtain good anatomical definition is T_1 weighting. The T_2 weighted images were found to be a sensitive method in disease detection.

Theory

In this discussion we will focus on the basic repeated RF spin echo and gradient spin echo experiments. The equation which describes the signal A_E at echo time in case of repeated spin echo and gradient echo experiment are given by [2,3]

$$A_E = \begin{cases} M_z^0 (1 - e^{-T_R/T_1}) e^{-T_E/T_2} \text{ - spin echo,} \\ M_z^0 \dfrac{1 - e^{-T_R/T_1}}{1 - \cos\alpha \cdot e^{-T_R/T_1}} \sin\alpha \cdot e^{-T_E/T_2^*} \text{gradient echo.} \end{cases} \quad (1)$$

where M_z^0 is the magnetization of the particular material in a certain main magnetic field, T_R is the repeat time and T_E the echo time. If we choose the flip angle to be 90º in case of the gradient echo, the two formulae in (1) become similar.

Let us consider that beside the useful signal coming from the imaged object A_{Euse} there is a residual signal A_{Eres} coming from the coil material, which for imaging purposes is desired to be undetectable. The condition of the latter of being "invisible" is to be smaller than the overall noise. This condition we will state by referencing to signal to noise ratio (SNR) as $A_{Euse} / A_{Eres} > SNR$. Let us define a function $SNR_{ij}[T_R, T_E]$ that relates tissue proton signal i to a spurious material proton signal j by

$$SNR_{ij}[T_R, T_E] = \frac{M^0_{z,use_i}}{M^0_{z,res_j}} \frac{1 - e^{-T_R/T_{1,use_i}}}{1 - e^{-T_R/T_{1,res_j}}} \frac{e^{-T_E/T_{2,use_i}}}{e^{-T_E/T_{2,res_j}}} . \quad (2)$$

Considering tissues and coil materials (Table 1) we can define the combined function

$$SNR_{total}[T_R, T_E] = \min[\{SNR_{ij}[T_R, T_E]\}, \{i, 1, N_{use}\}, \{j, 1, N_{res}\}] . \quad (3)$$

Generating a contour plot of (3) one can define a general diagram of acceptable T_E s and T_R s for a certain level of SNR.

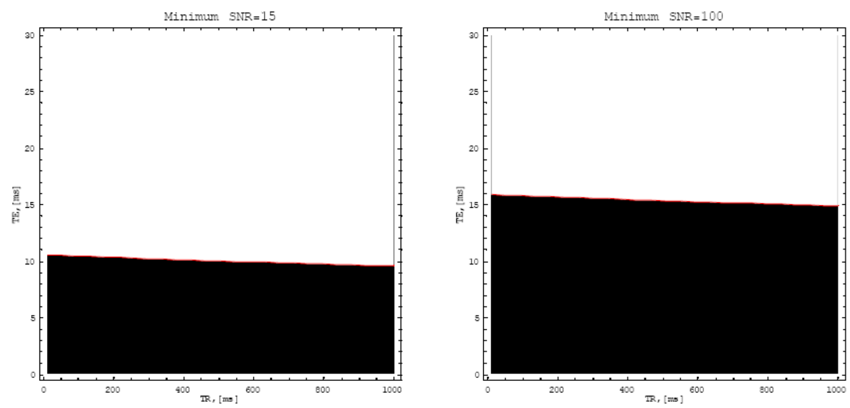

Figure 1. Permitted (white) and forbidden (black) regions for spin echo parameters (T_E and T_R), for two SNR values: 15 and 100. The two graphs are calculated in the approximation that the proton densities are the same for tissues and materials.

Material/Tissue	T_1, [ms]	T_2, [ms]
White Matter	390	90
Gray Matter	520	100
CSF	2000	300
Muscle	600	40
Fat	180	90
Liver	270	50
Kapton™	1200	2
Delrin™	800	2.8
Polycarb.	300	1
Nylon	1400	1.8

Table 1. T1 and T2 for common tissues and coil materials.

Results

Figure 1 shows contour plots generated from equation 3 for several tissues present in the human body and several materials present in a receive RF coil (Table 1), in the approximation that the volume concentration of protons are the same for all tissues and materials (crude simplification) for two levels of SNR_{total} (both 15 and 100). White represents the region where none of the residual materials are detectable and black is the region where some of the materials could be observed. Relaxation times for plastic materials are maximized; therefore acceptable region is shifted toward longer T_E s.

Conclusion

Hydrogen is a very difficult nuclei to eliminate from MRI coil materials. It is present in considerable concentrations in most types of the polycarbonates, commonly used materials in the Phased Array Receive coils. Beside this it can accumulate through moisture, which could be absorbed by some materials inside the coil. Plastic materials themselves exhibit several relaxation properties due to multiple phases (crystalline and amorphous) it could consist of. While the crystal-like components have $T_2 \ll 100\mu s$, the amorphous- like components have $T_2 > 1ms$ which was considered in the present calculation. It is important using MR relaxation times and hydrogen concentration in all materials in imaging volume, to estimate the ranges of imaging parameters like TE and TR. The expression (3) give the possibility, based on relaxation times and imaging parameters, by drawing Figure 1 –like diagrams to have a clear picture where spurious proton signal from coil materials is not affection the image .

References

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