Comparison Between Hahn Spin Echo and Gradient Echo Sampling of the Spin Echo (GESSE) T_2 Measurements at Ultra-High Field Strength

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Introduction: Knowledge of T_2 relaxation times at ultra-high field strength ($\geq$ 7 T) is needed for optimizing acquisition parameters for T_2-weighted imaging and understanding relaxation mechanisms. However, standard T_2 measurements (*e.g.*, using Hahn or Carr-Purcell-Meiboom-Gill Spin Echo (SE)) at ultra-high field strength are affected by severe radiofrequency (RF) magnetic field (B_1) inhomogeneity [1], which results in substantial variations of the flip angle and receive sensitivity across the field-of-view (FOV) [2]. Such T_2 measurements at 8 T were found to be accurate only in regions where the flip angle remains within ±20° from 90° [3]. The Gradient Echo Sampling of the Spin Echo (GESSE) T_2 measurement method was shown to be less sensitive to B_1 inhomogeneity at 1.5 T [4]. We implemented this method at ultra-high field strength and compared it with Hahn SE T_2 measurements in a phantom as well as *in vivo* and postmortem human brains. The B_1 inhomogeneity was also experimentally mapped to assess the B_1 sensitivity of both methods.

Methods: The studies were performed on an ultra-high field human whole-body MRI system using transverse electromagnetic RF head coils. Due to the flip angle variability, we first defined a "nominal" flip angle (FA) as the average flip angle in a 1 cm^3 region of interest (located in the hippocampus for human studies), determined the transmit power level resulting in a nominal FA of 90° using a voxel-selective stimulated echo sequence, and then used this reference to set the transmit power level corresponding to a chosen nominal FA. Four Hahn SE images were acquired with different TEs and a T_2 map computed by fitting a monoexponential decay pixel-by-pixel. For the GESSE method, a SE image was acquired at TE and two asymmetric SE images at TE ± ΔTE using readout gradients of same polarity to avoid misregistration errors due to gradient imperfections. A T_2 map was then computed as $T_2 = 2\,\Delta TE / \ln[S(TE - \Delta TE) / S(TE + \Delta TE)]$ [4]. Preliminary studies confirmed that the error is minimal when TE ~ T_2 and $\Delta TE > T_2/4$. To quantify the B_1 inhomogeneity, maps of the local flip angle α and receive sensitivity r were experimentally measured from two series of gradient echo images acquired with TR >> T_1 and nominal FA α_0 and $2\alpha_0$. A flip angle map was computed as $\alpha = \cos^{-1}(S_{2\alpha} / 2S_\alpha)$ [5], then a map of ρ r was computed as $S_\alpha / \sin(\alpha)$ and low pass filtered to yield a measure of the receive sensitivity.

To quantify the sensitivity of the T_2 measurements to B_1 inhomogeneity, we studied a 1.5 L phantom (4% agarose, 2 mM $CuSO_4$, 0.125 M NaCl, T_1 = 630 ms) using TR 3000 ms, TE 20/40/70/110 ms (Hahn SE) or TE/ΔTE 40/10 ms (GESSE), nominal FA 90°/180°, FOV (18 cm)^2, matrix (MTX) 256x128, one 3 mm thick slice for the T_2 measurements, and TE 7 ms, MTX 128x64, nominal FA 60°/120°, and otherwise identical parameters for the B_1 mapping. We also studied 5 healthy volunteers (2 male, 3 female, age 20–49) who gave informed consent and 5 postmortem unembalmed human subjects (2 male, 3 female, age 57–85). Typical parameters were TR 1500 ms, TE 20/50/90/135 ms (Hahn SE) or TE/ΔTE 50/13 ms (GESSE), nominal FA 90°/180°, FOV (16 cm)^2, MTX 512x256, one 3 mm thick slice for the T_2 measurements, and TR/TE 4000/7 ms, nominal FA 60°/120°, MTX 256x64, and otherwise identical parameters for the B_1 mapping.

Results: Figure 1 shows the results of the phantom study. The GESSE T_2 map is more homogeneous than the Hahn SE T_2 map and the GESSE T_2s are generally lower than the Hahn SE T_2s. The banding artifacts in the GESSE T_2 map can be attributed to shim/gradient instability. As expected, there are substantial variations of the flip angle and receive sensitivity. The Hahn SE T_2s tend to increase as the flip angle deviates from 90°, whereas the GESSE T_2s are independent of the flip angle. Both Hahn SE and GESSE T_2 measurements become noisier as the flip angle decreases. The average Hahn SE T_2 at a flip angle of 90° is higher than the average GESSE T_2.

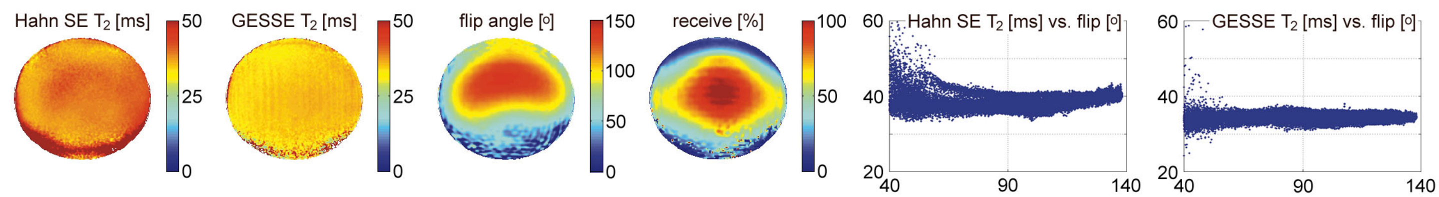

Figure 1: Results of the phantom study. On both plots, pixels with a receive sensitivity lower than 25% and therefore excessive noise were excluded.

Figure 2 shows the results of an *in vivo* study. In the central region where flip angles are much larger than 90°/180°, Hahn SE T_2s are very high, as in the phantom. In the lateral parts of the temporal lobes where the flip angles and/or receive sensitivity are low, both Hahn SE and GESSE methods become inaccurate and Hahn SE T_2s are again very high. On the other hand, in regions where flip angles are close to 90°/180°, both methods provide similar results, with GESSE T_2s somewhat lower than Hahn SE T_2s, as in the phantom. Furthermore, the GESSE T_2 map clearly shows some nuclei with lower T_2s (arrows), which are not seen on the Hahn SE T_2 map. As for the phantom, banding artifacts in the GESSE T_2 map can be attributed to system instability.

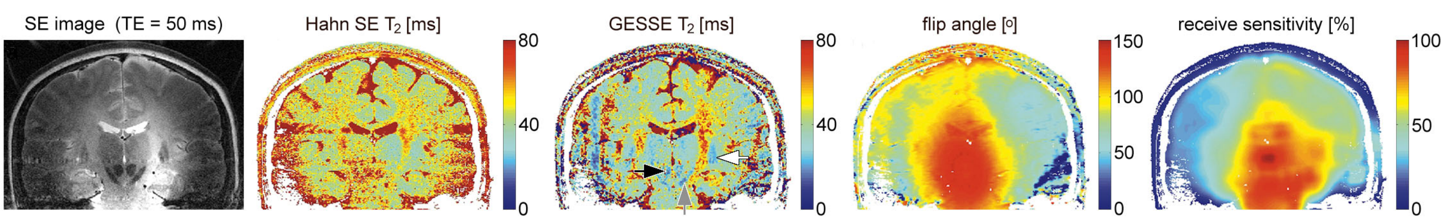

Figure 2: Results of an *in vivo* study (29-year-old female). Black arrow = red nucleus, gray arrow = substantia nigra, white arrow = globus pallidus.

Discussion: The GESSE method offers significant advantages over the Hahn SE method. First, it requires a substantially shorter scan time (25% in our case) and is thus more suitable for *in vivo* studies. Second, it is less sensitive to B_1 inhomogeneity, which is severe at ultra-high field strength. Furthermore, one reason why Hahn SE T_2s are higher than GESSE T_2s may be that the Hahn SE signal decay is not simply monoexponential but depends on water diffusion in magnetic field gradients [6], especially in the nuclei. The GESSE method is by design not affected by this effect [4], and therefore provides more accurate T_2 measurements. On the other hand, GESSE T_2 maps are noisier than Hahn SE T_2 maps. This is because the former are computed from only two images, whereas the latter are computed from four. The short T_2s at ultra-high field strength limit the TE and therefore the number of echoes that can be acquired. In addition, the GESSE T_2 maps are computed from a ratio of images, which is more sensitive to error propagation than the exponential fit used to compute the Hahn SE T_2 maps.

Conclusion: The GESSE method is significantly faster, less sensitive to B_1 inhomogeneity, and more accurate than the Hahn SE method, thus making it clearly preferable for T_2 measurements at ultra-high field strength, despite the lower signal-to-noise ratio.

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