Blipped mGESEPI (bmGESEPI) for Fast and Accurate T_2^* Measurements with B_0 Inhomogeneity Compensation

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Introduction: Knowledge of T_2^* relaxation times at ultra-high field strength (≥ 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 multi-echo gradient echo (GE)) are affected by static magnetic field (B_0) inhomogeneity, which is particularly severe at ultra-high field strength. The multi Gradient Echo Slice Excitation Profile Imaging (mGESEPI) method was developed for T_2^*-weighted imaging and T_2^* measurement with B_0 inhomogeneity compensation [1,2]. We implemented this method at ultra-high field strength, but realized that it requires excessive acquisition times to provide accurate T_2^* measurements. We therefore developed a more efficient method that allows significantly faster and accurate measurements, and demonstrate these advantages in a phantom as well as *in vivo* and postmortem human brains.

Theory: In the mGESEPI method, a compensation gradient G_c is combined with the slice rephaser gradient, a train of M GE images are acquired at different TEs, and this is repeated for N equidistant G_c values. For each echo, an image is reconstructed by 3D Fourier transform followed by partial summation along the slice direction. A T_2^* map is then computed by fitting a monoexponential decay pixel-by-pixel to the M images. The susceptibility-induced gradient in the slice direction $G_{z,susc}$ that can be compensated for by a given G_c at a time TE is given by $\int G_c(t)\,dt = G_{z,susc}\,TE$. Since the $G_{z,susc}$ that can be compensated for decreases as TE increases, the T_2^* measurements are accurate only if the largest G_c ($G_{c,max}$) is able to compensate for the largest $G_{z,susc}$ at the last echo. However, satisfying this condition at ultra-high field strength requires a large $G_{c,max}$ and N, resulting in excessive acquisition times for *in vivo* studies.

We developed a new method based on the mGESEPI method in which the compensation gradient G_c is also added as a blipped gradient in the slice direction between each echo acquisition (Figure 1). As such, $\int G_c(t)\,dt$ increases linearly with TE, so that the same $G_{z,susc}$ is compensated for at each echo. For the T_2^* measurements to be accurate, the $G_{c,max}$ required to compensate for the largest $G_{z,susc}$ is a factor M smaller than in the mGESEPI method, thus allowing a reduction of N as well as the acquisition time by the same factor. This so-called blipped mGESEPI (bmGESEPI) method is therefore more efficient and allows significantly faster and accurate T_2^* measurements.

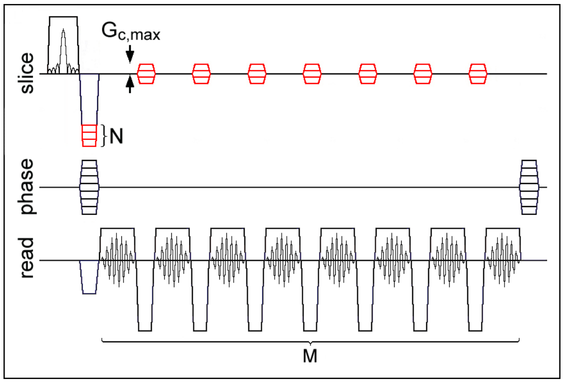

Figure 1: bmGESEPI pulse sequence.

Methods: The studies were performed on an ultra-high field human whole-body MRI system using transverse electromagnetic RF coils. T_2^* maps were acquired in a phantom (air-filled tube orthogonal to B_0 surrounded by a $CuSO_4$ solution) using the multi-echo GE, mGESEPI, and bmGESEPI methods with equivalent parameters, namely TR 100 ms, interecho spacing ΔTE 3.5 ms, M 10, field-of-view (FOV) $(8\ \mathrm{cm})^2$, matrix (MTX) 128^2, one 3 mm thick slice, $G_{c,max}$ 160% (of the slice rephaser gradient) and N 80 (mGESEPI) or $G_{c,max}$ 16% and N 8 (bmGESEPI). In addition, T_2^* maps were reconstructed using only partial data from the original mGESEPI data set, thus simulating mGESEPI acquisitions with a range of smaller N values and either the same $G_{c,max}$ / N ratio or $G_{c,max}$ as the original data set. We also studied 2 healthy volunteers (2 male, age 32–34) who gave informed consent and 4 postmortem unembalmed human subjects (1 male, 3 female, age 57–84). For the *in vivo* study shown below, T_2^* maps were acquired using the GE and bmGESEPI methods with TR 500 and 100 ms respectively, ΔTE 4.4 ms, M 10, FOV $(18\ \mathrm{cm})^2$, MTX 256^2, one 3 mm thick slice, $G_{c,max}$ 20% and N 16 (bmGESEPI).

Results and Discussion: Figure 2 shows the results of the phantom study. The GE T_2^* map clearly shows artifacts due to B_0 inhomogeneity. These artifacts can be largely corrected for by the mGESEPI method with $G_{c,max}$ 160% and N 80, as shown by the more homogeneous T_2^* map, however at the cost of a long acquisition time. As expected, decreasing both $G_{c,max}$ and N progressively reduces the amount of correction, as shown by the artifacts appearing around the tube on the mGESEPI T_2^* map with $G_{c,max}$ 16% and N 8. Reducing only N while keeping the same $G_{c,max}$ also results in artifacts, as seen on the mGESEPI T_2^* map with $G_{c,max}$ 160% and N 8, because the spacing between the G_c values becomes too large (*i.e.*, the oversampling becomes insufficient) for an accurate reconstruction of the images. On the other hand, the bmGESEPI method can provide a B_0 inhomogeneity compensation that is even better than that achieved by the mGESEPI method with $G_{c,max}$ 160% and N 80, as shown by the very homogeneous T_2^* map, while requiring only 10% of its acquisition time. These results clearly show the significant advantages of the bmGESEPI method over the mGESEPI method.

Figure 3 shows the results of an *in vivo* study. The GE T_2^* map shows very low values with no clear depiction of the anatomy due B_0 inhomogeneity, whereas the bmGESEPI T_2^* map shows higher values with a clear delineation of anatomical structures such as the lateral ventricles, putamen, and globus pallidus. The high T_2^* values in the right posterior cortex are due to B_1 inhomogeneity (*i.e.*, low flip angle and/or receive sensitivity), as typically observed on axial images of the human brain acquired at ultra-high field strength. While the parameters still need to be optimized in further studies, these results clearly show the effectiveness of the bmGESEPI method for *in vivo* T_2^* measurements.

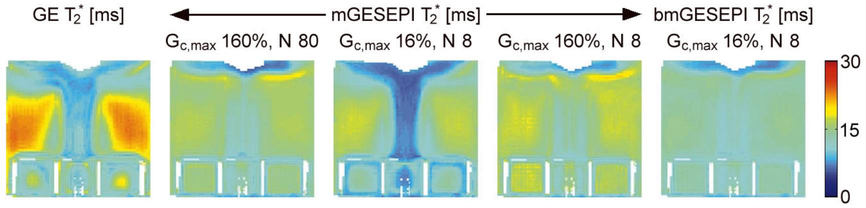

Figure 2: Results of the phantom study.

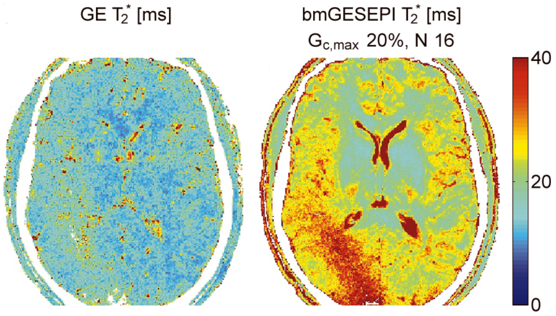

Figure 3: Results of an *in vivo* study (34-year-old male).

Conclusion: We developed a new method for T_2^*-weighted imaging and T_2^* measurement with B_0 inhomogeneity compensation that is more efficient than the existing mGESEPI method and allows significantly faster and accurate T_2^* measurements. This method will be particularly useful at ultra-high field strength, which is affected by severe B_0 inhomogeneity.

References: [1] Yang QX. *Proc 6th ISMRM* 1998. p. 578 [2] Liu H. *Proc 9th ISMRM* 2001. p. 1352