Accurate $T_2$ Contrast when using Magnetization Preparation Sequences

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Introduction:
Magnetization preparation sequences provide a practical means to acquire $T_2$-weighted images rapidly [1,2]. By scanning different parts of k space within a series of small-tip angle excitations, $T_2$-weighted images can be acquired in less than a second. Due to this method’s utility and the clinical importance of accurate $T_2$ contrast in a $T_2$-weighted image, the magnetization preparation sequence is now included as a stock sequence on many whole-body MR imagers.

However, most implementations of magnetization preparation sequences rely on a $90°/90°/z$ pulse pair for excitation and tip-up. Self-compensation for RF field offsets ($\Delta B_1$) when using this pulse pair introduces a $T_2$ contribution into the longitudinal stored $T_2$ contrast. This effect is inherent to all $\pm \theta/\mp \theta$ magnetization preparation sequences and cannot be addressed easily using phase-cycling methods. Within a $T_2$ measurement, the resultant $T_2$ measurement error is greater than 5% for $\Delta B_1 > 12\%$. With $\Delta B_1$ in vivo typically on the order of 15 - 20% [3], there is significant room for improvement in current $T_2$-weighted magnetization preparation sequences. We have demonstrated that the implementation of relatively simple composite $90°$ pulses for both excitation and tip-up provides an appropriate solution to this problem.

Method:
$T_2$-weighted images were acquired using the following pulse sequence. The excitation pulse was followed by a MLEV pattern of $90°/180°/90°$, composite refocusing pulses [4]. The $T_2$ contrast was then tipped up to the longitudinal axis and imaged using a spectral-spatial excitation pulse followed by a spiral readout gradient. The refocusing interval was 24 ms. $T_2$ contrast was preserved following the preparation interval using an RF cycling scheme [5]. TR was long (4 seconds).

The accuracy of the $T_2$ contrast was evaluated using simulated and experimental $T_2$ measurements from a MnCl₂-doped water phantom ($T_2 = 160 \pm 2$ ms). The simulation is described elsewhere [4]. Experimental measurements were performed on a 1.5 T GE Signa using the body coil to transmit. $T_2$'s were calculated as a weighted-least squares fit to the mean signals within each region of interest, using $T_2$-weighted images acquired at four echo times (TE = 11, 57, 104, and 197 ms). The echo times were shifted to account for $T_1$ signal decay effects during each composite refocusing pulse [4].

To verify the effects of the excitation and tip-up pulses during the preparation interval, $T_2$ error was mapped to $\Delta B_1$ and static field offsets ($\Delta B_0$) using three excitation and tip-up pulse pairs: 1) $90°$ excitation/$90°/90°$ tip-up; 2) $45°_{-90°}/90°/45°_{x}$ excitation/$45°_{-90°}/90°/45°_{x}$ tip-up; and 3) $360°_{-270°}/90°/90°_{x}$ excitation/$360°_{-270°}/90°/90°_{x}$ tip-up. The first pulse pair represents the simplest possible sequence design and the most common one in current $T_2$-weighted magnetization preparation sequences. The latter two designs implement relatively simple composite $90°$ pulse pairs which have better $\Delta B_1$ and/or $\Delta B_0$ properties than the $90°/90°$ pulse pair [6]. The $45°_{-90°}/90°/45°_{x}$ pulse compensates for $\Delta B_1$ at the cost of a three-fold increase in pulse duration. The $360°_{-270°}/90°/90°_{x}$ pulse provides dual $\Delta B_0$ and $\Delta B_1$ compensation at the cost of an eight-fold increase in pulse duration. For comparison, $T_2$ error mapping was also performed using a $T_2$ measurement with the same refocusing train and data acquisition method, but without the tip-up pulse [4]. This sequence avoids the problems associated with storing $T_2$ contrast in $M_z$ at the cost of reduced flexibility. The effects on $T_2$ of imperfections in the excitation pulse were addressed using RF cycling. All studies were performed over $\Delta B_0 \pm 2$ ppm and $\Delta B_1 \pm 25\%$ of the ideal RF amplitude ($\gamma \Delta B_{1,nom} = 616$ Hz).

Results:
We display the maps of $T_2$ error as contour plots (Fig. 1). Each point on these plots depicts the $T_2$ error which results at a given $\Delta B_0$ and $\Delta B_1$ corresponding to a voxel in the reconstructed images.

![Figure 1: Mapping of $T_2$ error to $\Delta B_0$ and $\Delta B_1$ when $\gamma \Delta B_{1,nom} = 616$ Hz. The contour lines illustrate 5% error in $T_2$ for experimental (solid) and simulated (dashed) data respectively.](image)

The operating region for the $T_2$ measurement without the tip-up pulse extends to about $\pm 1.5$ ppm in $\Delta B_0$ and $\pm 20\%$ in $\Delta B_1$. Based on these constraints, the magnetization preparation sequence using the $90°/90°/z$ pulse pair is inadequate, with an operating region which extends to only $\pm 1$ ppm in $\Delta B_0$ and to $\pm 12\%$ in $\Delta B_1$. The $45°_{-90°}/90°/45°_{x}$ pulse pair provides $\Delta B_1$ insensitivity, yet its $\Delta B_0$ sensitivity is excessive. The $360°_{-270°}/90°/90°_{x}$ pulse pair performs well for $\Delta B_1$ within 15-20% and $\Delta B_0$ within $\pm 1.3$ ppm. This performance is sufficient for many applications in vivo [3,7]. If required, further $\Delta B_0$ insensitivity can be gained by increasing the RF amplitude.

Discussion:
$\Delta B_1$ effects on the excitation-tip-up pulse pair bias the $T_2$-weighting of conventional magnetization preparation sequences excessively. Use of a $360°_{-270°}/90°/45°_{x}$ pulse pair for excitation and tip-up ensures an accurate $T_2$-weighting for $\Delta B_1$ within $\pm 15-20\%$ and $\Delta B_0$ within $\pm 1.3$ ppm, when $\gamma \Delta B_{1,nom} = 616$ Hz. The improved method has value for improving $T_2$-weighted images and for determining accurate measures of $T_2$ in vivo.

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