Validation of B1+ Non-uniformity Correction in the Chest at 3T using TIP-COMP

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Introduction: Non-uniform B1 transmission (B1+) produces spatially varying flip-angles, causing intensity and contrast to be non-uniform which is an essential source of error for quantification of NMR parameters. In high field cardiac imaging, B1+ inhomogeneity tends to vary smoothly and primarily along one direction over the heart [1,2]. In this work, generalized Transmit In-Plane Compensation (TIP-COMP) RF pulse design, in-vivo validation, and real-time B1+ measurement and compensation are presented.

Methods and Results:

Generalized TIP-COMP RF pulse design: New RF pulse designs to compensate for approximately linear in-plane B1+ variation was presented in 2005 [3]. This method utilized 2DRF flyback EPI design where subpulse spacing and relative phase in k-space was used to fit the linear region of a raised cosine profile to the B1+ profile, while individual subpulses produced slice selection. The in-plane profile variation (raised cosine) can be examined to find the region that best fits profile variation with an additional control parameter ($\angle$RF) instead of using only the linear region of the raised cosine profile. Figure 1 illustrates the three control parameters of TIPCOMP, **$\angle$RF – location of variation** (Fig. 1 a-c), **the radial direction ($\vec{r}$) – primary B1+ variation direction** (Fig 1 d-f), and **Δk_r - amount of variation** (Fig.1 g-i). The control parameters can be calculated, based on the measured B1+ profile, using curve fitting. The RF subpulse duration was minimized to 0.5 ms, while the overall pulse duration including the refocusing gradient lobe was 3.024ms, which is sufficiently fast for cardiac imaging. This excitation pulse sequence produces a 5 mm slice thickness. With an increased number of subpulses, generalized TIPCOMP can employ optimized FIR filter design to find subpulse amplitudes and phase that best compensate the in-plane B1+ variation. The desired in-plane profile, gradient amplitude and slew rate, peak B1+ and SAR, and pulse duration can all be considered as constraints, and convex optimization methods may be applied to quickly design excitation pulses on a subject-by-subject basis, that probably minimize flip-angle variation.

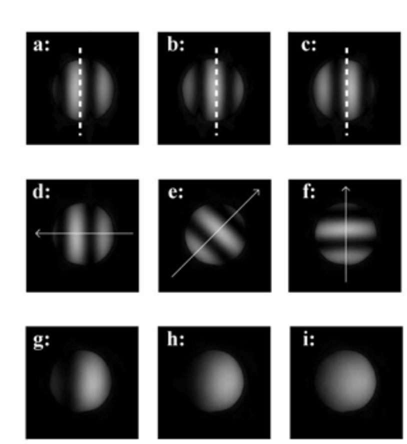

Fig. 1: TIP-COMP control parameters: $\angle$RF (a - c), $\vec{r}$ (d – f), and Δk_r (g – i).

Validation in the Chest at 3T: Experiments were performed on a GE Signa EXCITE HD 3.0T system with gradients capable of 40 mT/m amplitudes and 150 T/m/s slew rates, and receiver supporting 4 µs sampling (±125 kHz). The saturated double angle method (SDAM) [2] was used to acquire flip-angle maps. A spiral SDAM sequence was modified to include the TIP-COMP pulse in order to compare the images with conventional and TIPCOMP RF pulses. Cardiac-gated spiral images were acquired within a breath-hold. Figure 2 contains flip-angle maps in the abdomen of a healthy volunteeer with a conventional RF pulse and dynamically adjusted TIP-COMP pulse. The ROI (12cm) covers a large portion of the liver and the percentage flip-angle variation over the ROI, measured as $(\alpha_{max}-\alpha_{min})/\alpha_{max}$, was reduced from 15.5% to 8.3%. Figure 3 contains flip angle maps from a short-axis cardiac view in a healthy volunteer. The ROI (10cm) covers the whole left ventricle and the percentage flip-angle variation was reduced from 30.1% to 7.9%.

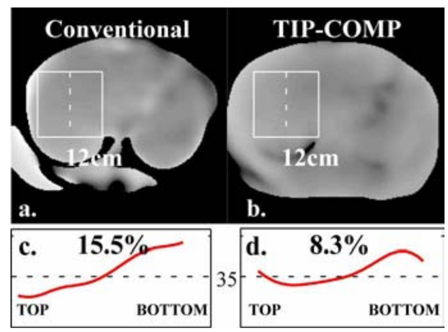

Fig. 2: Abdominal B1+ compensation. Measured flip-angle distributions (black = 20 degrees, white = 60 degrees) (a and b) and cross-section plots (dotted line) (c and d).

Real-Time Measurement and Compensation: To avoid the rapid measurement and compensation of flip angle variations, SDAM B1+ measurement and TIPCOMP B1+ compensation were implemented within a custom real-time imaging system [4]. Cardiac gating was used, and each measurement consisted of fat saturation followed by a single shot image acquisition and SDAM reset pulse. B1+ maps were acquired every two heart-beats, and the TIPCOMP design parameters could be adjusted dynamically. Short-axis cardiac images were acquired with the real-time imaging system. 26.7 % flip-angle variation over the left ventricle (ROI = 6.5cm) was measured and reduced to 14.4 % on-the-fly using real-time TIPCOMP (images not shown).

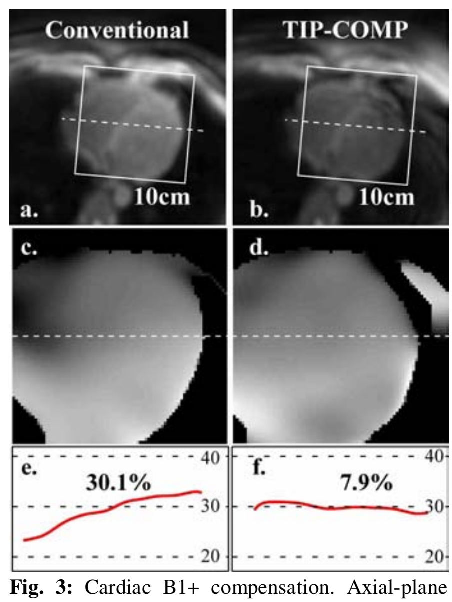

Fig. 3: Cardiac B1+ compensation. Axial-plane cardiac images (a and b), measured flip-angle distributions (black=20, white=40) (c and d), and cross-section plots (dotted line) (e and f).

Conclusion: TIPCOMP RF pulse design has been generalized to include new "degrees of freedom" and compensate for non-linear B1+ variations. TIPCOMP has also been validated in-vivo at 3T for liver and cardiac applications. Finally SDAM measurement and interactive TIPCOMP design has been implemented for extremely rapid and iterative adjustment of excitation profiles. TIP-COMP reduced B1+ variation over the heart at 3T by nearly a factor of four compared with a conventional RF pulse. This reduction of the B1+ variation is particularly important for high field imaging and quantitative imaging.

References

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[3] Sung K., et al., Proc. 13th ISMRM p.18 (2005) [4] Santos, et al., IEEE EMBS 26th, 1048 (2004)