Characterizing in vivo B1 Maps at 7T using the Kolmogorov-Smirnov Test

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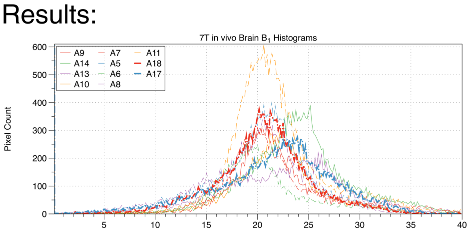
Target Audience: Physicists, engineers, data analysts, system designers

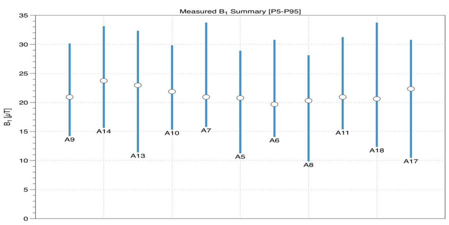
Purpose: To develop a robust statistical method to characterize the similarity of derived |B1| maps in phantoms and human subjects to allow more robust comparison of subject, coil, and system performance over time and across subjects, and to identify typical performance across adult human subjects to facilitate optimization of RF coils and pulse sequences for human studies at 7T.

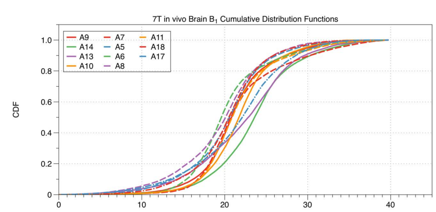
Methods: All studies were performed on a GE Signa MR950 7T human research system (GE Healthcare, Waukesha, WI) using a quadrature transmit 32 channel receive array (Nova Medical, Wilmington, MA). Human studies were performed with informed consent under a protocol approved by the Committee on Human Research at UCSF. The B_1 maps were acquired in the course of other studies on adults and included both volunteers with no known health issues and patients with multiple sclerosis. B_1 magnitude maps were generated using the Bloch-Siegert method[1] with an optimized phase modulated RF pulse[2], reconstructed to give the equivalent maximum B1 magnitude at each location at full transmitter gain. 5 mm axial slices were acquired (some with a 5 mm gap and some with contiguous slices) over the head on a 64 by 64 matrix, with the field of view adjusted to ensure full coverage. A 2 ms phase modulated Bloch-Siegert encoding pulse with an equivalent nominal flip angle of 150 degrees was used.

Masking was applied to set the background signal to 0. Histograms were generated in 256 bins with the maximum value set to accommodate all the datasets. The bin containing 0 was excluded from further analysis but by visual inspection this bin contained only background pixels. Histograms were plotted on a common axis for direct comparison (Figure 1). Median and interquartile range are shown in Figure 2. The cumulative distribution function (CDF) was generated by integrating the histogram and normalizing by the total number of pixels (Figure 3), bringing all CDFs to a common scale. The Kolmogorov-Smirnov (KS) statistic was calculated as the maximum absolute difference between pairs of CDFs.

Results:







	A9	A14	A13	A10	A7	A5	A6	A8	A11	A18	A17
A9		1.81425E-10	5.73588E-06	6.68170E-02	9.24820E-01	2.54720E-01	2.26050E-03	7.32270E-03	9.99969E-01	4.17280E-01	4.98920E-03
A14			2.29410E-02	5.30294E-06	2.21188E-09	7.92780E-18	7.92780E-18	2.83323E-14	6.08593E-10	1.24765E-12	6.92880E-03
A13				7.55892E-04	1.65772E-04	4.81575E-07	1.31239E-09	2.98293E-08	2.16692E-05	1.93780E-07	3.21750E-01
A10					3.32570E-02	1.07730E-02	8.07704E-08	1.49699E-04	1.16063E-01	5.77640E-03	1.06352E-01
A7						7.47590E-02	1.11060E-02	2.65077E-03	9.32280E-01	1.96270E-01	1.80860E-02
A5							6.11231E-02	7.17996E-01	6.46090E-02	9.99990E-01	6.20670E-04
A6								1.57656E-01	1.77620E-03	8.29460E-02	2.54940E-07
A8									1.97010E-03	4.76121E-01	4.38782E-05
A11										2.08723E-01	8.40960E-03
A18											4.38782E-05

Discussion: Figure 1 shows the B1 histograms over the whole head for 10 volunteers. Figure 2 shows the 5th to 95th percentile ranges of the B1 distributions; and Figure 3 shows the cumulative distribution functions for the histograms. Subject A11 had twice as many slices in the image set as the others, hence the higher peak in the histogram, but the CDF was comparable to the others. Table 1 shows the p values for the KS test statistic[3]; highlighted cells have p<0.001, indicating a statistically significant difference after Bonferroni correction for 10 comparisons (equivalent to p<0.01 for a single comparison). A13, A14, and A17 appear to have different B1 distributions from the others, but are themselves essentially similar. In all but one case the median B_1 at full power exceeded 20 μT, and the mean median B_1 across all 10 subjects was 21.38 μT with a standard deviation of 1.22 μT, a coefficient of variation of 5.7%.

Conclusion: Despite variation in head size and shape; positioning of the head within the coil; and positioning of the coil on the patient table, the B_1 maps were highly consistent, and the KS test proved quite effective in characterizing the (lack of) differences between the maps

References:

1. Sacolick L, et al. MRM 63 (5) pp 1315-22. 2010 2. Khalighi M, et al. MRM 70(3) pp 829-35. 2013 3. Press W et al., Numerical Recipes in C, 2e 1997 pp 620-8.