Initial Experience with RF shimming at 3T using a whole body 8 channel RF system

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INTRODUCTION:

Higher field MR scanners offer advantages in signal to noise ratio, but suffer from radio frequency (RF) inhomogeneity which causes spatial variability in both excitation and receive fields even when using enveloping coils that would provide spatially uniform fields at lower field strengths. Non uniformities in these fields generate signal and contrast modulation in the final images. The use of multiple transmit elements with independent drive can provide greater control of transmitted RF fields and has been shown to provide a capability for efficient RF shimming ([1,2], in which optimised independent drive pulses are sent to each element so that their sum provides a more uniform excitation field. Early experiments with prototype systems and mostly on phantoms have shown promise. We present our first in vivo experience of RF shimming on healthy volunteers using an eight channel whole body 3T MRI system.

MATERIALS and METHODS:

Experiments were conducted on a 3T Philips Achieva system (Best, The Netherlands) modified to include a multi channel whole body transmit system consisting of 8 TEM resonators and extended radio frequency (RF) system [3,3a]. The multi element body coil could be used in two modes: as a single whole body resonator, with all elements driven in fixed amplitude and phase relations (so-called “compatibility mode”), and in full multi-channel mode fed by separate low level RF generators and power amplifiers with full independent amplitude and phase control. In this study we compared the two modes. All experiments used the multi-channel body coil for signal reception and data was pre-combined to yield a single output signal. In-vivo RF field (B1) maps were obtained separately for each transmit coil element employing the AFI technique [4] with a total acquisition time of 138s for all coil elements. AFI, employs a duel TR steady state multi-slice sequence with Field of View (FOV) 400mm, 64 scan matrix, 75° flip angle, TR1 = 40 ms, TR2 = 200 ms and 2 averages and yields amplitude B1 maps for each element, the phase was determined directly from the calibration images. RF shimming was achieved by optimizing the linear sum of these sensitivity maps with complex weights (“drives”), to be determined. The deviation from a target field that was uniform in amplitude, was minimised without phase constraint [5] using a non-linear least squares solver (lsqnonlin algorithm, Matlab, Mathworks). A multiple start strategy was adopted to minimize risk of stopping in local minima. The resulting drives were applied to the individual RF channels and for comparison a uniform drive was used on all coils. Three adult male volunteers were studied, with two subjects being imaged twice. All had similar BMI (22-24). In each case, following normal static field (B0) shimming and the multi channel RF calibration, transverse field echo images of the pelvis were obtained (FOV: 400x 240 mm² (rectangular FOV), 256 scan matrix, TR: 10ms, TE: 2.6ms, flip angle 7.5 or 15 deg). All data was processed off line using Matlab and images were evaluated for excitation homogeneity. In addition the relative amplitudes and phases of the required RF drive pulses were compared between subjects and the optimised calculated B1 maps were compared to the linear sum.

RESULTS:

The B1 calibration procedure was successfully completed in all examinations. Figure 1 shows a comparison of pelvic images from one of the volunteers with an unoptimised linear sum(on left) and shim mode (on right). There is signal variation in both images which we attribute to receiver sensitivity variation, but the shimmed result shows increased signal in a region of low B1 that is present in the compatibility mode data (arrow). This is typical of all the examinations in this study. Assessment of these regions of signal loss confirmed signal recovery in all 5 examinations, recovering contrast and allowing anatomy that was poorly visualised in the combined mode images to be more clearly seen.
A radiologist assessed the images for homogeneity and quality on a scale of 1 (poor) to 5 (excellent). Mean results for the unoptimised linear sum images were: 2 (homogeneity) and 2.7(quality) and for the shimmed images were 3.7 and 4.
Analysis of the shim drives showed that all coils were being driven within +/- 45 degree phase shifts compared to their optimal settings in combined mode. This confirmed that system performance could be optimised by individual shim calculation but that this optimisation did not result in phase cancellation which would imply loss of efficiency in excitation and could lead to increased SAR values. The shim drives resulted in a mean SAR as estimated by the sum of square drives across all coil elements of 61% with a range of 23% to 81% relative to the unoptimised linear sum. The RF homogeneity as assessed by root mean squared deviations from uniformity averaged over the subject area were reduced from 38% in combined mode to 21% when shimmed.

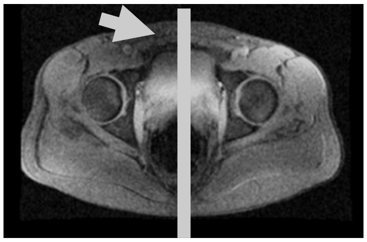

Figure 1. Example with combined mode on left and shimmed mode on right. Note region of signal loss is filled in by the shimming

CONCLUSION:

RF shimming allows substantial control of excitation homogeneity. At 3T it is common to observe regions of signal drop-out when imaging the abdomen in larger subjects (we routinely observe this with conventional birdcage transmit coils). By using a simple RF shimming procedure in which individual transmit elements are calibrated and then their combination optimized on a per subject basis, these regions of signal loss could be mitigated. Although even greater control can be achieved using independently tailored excitations [5] the currently adopted simple shim approach has the virtue that it can be directly applied to all conventional sequences, making the benefits of multi-channel transmit directly available for all MRI examinations. The inter subject variation in relative drive phase between coils indicates that subject specific calibration is required for this method to be maximally effective. Another potential benefit in this pilot study of individual shimming of the transmit field is reduction in SAR. The present work is part of an ongoing development towards providing safe and efficient operation of multi-channel transmit on an otherwise standard system in a hospital setting for routine use on patients.

References 1) Ibrahim TS et al., MRI 18 (2000) 733, 2) Seifert F et al., ISMRM 10 (2002) 162 3**)** Graesslin et al Proceedings ISMRM 2006, p 129 3a) Vernickel P et al., MRM 58 (2007) 381, 4) Yarnykh VL. Magn Reson Med. 2007;57(1):192-200, 5) Katscher U et al., Proceedings ISMRM 2007, p 1693.