MR Physics for Physicists / B_1 Shimming and Parallel Transmission

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Highlights

- Inhomogeneities of B_1 at high main field strengths can be mitigated by parallel transmission.
- (Accelerated) multidimensional RF pulses allow further improvement of B_1 homogeneity.
- B_1 shimming and parallel transmission open new possibilities for SAR management.

Target audience:
(Ultra-)high field MRI and RF physicists / engineers and users interested in parallel RF excitation and pulse design for research and clinical applications.

OUTCOME/Objectives:
Learners will understand the principles of parallel transmission as an important prerequisite for a correct, efficient, and safe application of B_1 shimming for (ultra-)high field MR imaging.

PURPOSE:
In high field MR, wave propagation effects are able to build up local flip angle maxima and minima, leading to significant signal and contrast inhomogeneities in the reconstructed images (see, e.g., [1]). Without removing or sufficiently reducing these B_1 inhomogeneities, the diagnostic value of the images may be compromised.

METHODS:
Currently, among other means, modifications of the applied RF pulses are investigated to cope with the mentioned B_1 inhomogeneities. First, using a coil array for RF transmission, standard slice selective pulses can be transmitted with different weights in the different array elements (see, e.g., [2-4]). These weights, i.e., amplitude and phase of each element, are designed to yield a flip angle variation as small as possible ("basic" B_1 shimming). On the other hand, a two- or three-dimensional RF pulse can be applied, whose target pattern corresponds to the reciprocal of the B_1 inhomogeneity to be compensated. Thus, the resulting flip angle should be constant across the field of excitation ("tailored" B_1 shimming). Using not a single RF transmit coil, but again a transmit coil array, the required multi-dimensional RF pulses can be based on short trajectories, which are "sparse" in the excitation k-space. The resulting gaps in the excitation k-space can be filled by utilizing the different sensitivity profiles of the elements of the transmit coil array used ("Transmit SENSE", see, e.g., [5-9]). These sensitivity profiles have to be measured in a preparation step prior to scanning (so-called "B_1-mapping", see, e.g., [10-13]), both for basic as well as for tailored RF shimming.
A much debated topic for B_1 shimming and parallel transmission is the specific energy absorption rate (SAR) in the framework of RF patient safety (see, e.g., [14-17]). On one hand, the new degrees of freedom introduced by parallel transmission remove the proportionality of RF power and SAR as found for single channel systems. RF safety concepts have to be adapted accordingly, which is a highly non-trivial challenge for RF pulse design as well as for online RF/SAR monitoring. On the other hand, parallel transmission also offers the possibility to reduce SAR, and thus, to fully exploit the capabilities of the MR system used.

RESULTS:
Numerous *in vivo* studies have investigated and utilized B_1 shimming and parallel transmission. Transmit arrays used range from two elements in commercial systems up to 64 elements in research. B_1 shimming and parallel transmission have been reported for main field strengths of 3T, where the technique is applied, e.g., for abdominal, cardiac, and breast imaging, as well as for 7T and above. The figure demonstrates exemplarily the effect of basic B_1 shimming on cardiac imaging at 3T using two RF transmit channels [18], resulting in a more homogeneous signal and improved image contrast.

DISCUSSION / CONCLUSION:
B_1 shimming and parallel transmission is a key element to enable high field and ultra-high field MRI at maximum image quality and RF patient safety.

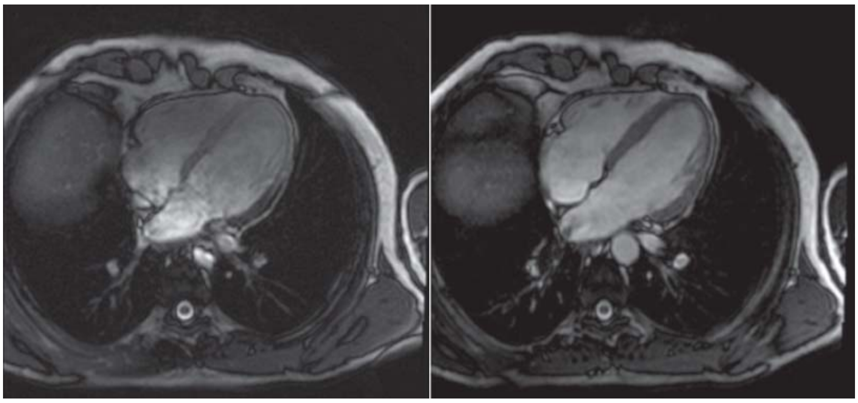

Figure: Exemplary demonstration of basic B_1 shimming for cardiac imaging at 3T [18], resulting in a more homogeneous signal and improved image contrast (right) compared to conventional RF transmission (left). The end-diastolic steady-state free precession (SSFP) images in horizontal long-axis orientations have been acquired using two channels for RF transmission and a six-element phased-array coil for signal reception.

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