Flexible Feature Specific Inner-Volume Selection with Transmit SENSE: Methods and Applications in Humans, Animals and Biological Samples

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Introduction: The theoretical concept of Parallel Excitation or Transmit SENSE [1,2] has been known for several years now, but due to hardware limitations that had to be overcome only recently fully experimental implementations of the technique have been achieved [3,4,5,6]. In these studies the predictions of the Transmit SENSE theory have been confirmed by basic experiments of multi-channel spatially selective excitation with different setups and different degrees of acceleration. In the present study the Transmit SENSE technique has been evaluated for biological and medical applications. First in-vivo experiments of inner-volume selection in a rat and on a human subject have been performed and the feasibility of double parallel TX/RX imaging has been evaluated in a biological sample.

Materials and Methods: The experiments in this study were carried out on a 4.7 T BioSpec animal scanner and on a 3 T MedSpec whole body system (Bruker BioSpin MRI GmbH, Ettlingen, Germany). For the experiments in the rat an integrated coil setup was used [7] consisting of a 3-element TX-only current-sheet-antenna (CSA)-array for applying the Transmit SENSE pulses, a birdcage-type resonator for homogeneous slice-selective refocusing and a RX-only quadrature surface-coil for signal reception. The experiments on the human subject were performed with a 4-element TX/RX CSA-array [8]. Furthermore, a 3-element TX/RX surface-coil array, designed for mouse head imaging, was used for a feasibility study in a cherry tomato.
The in-vivo images were acquired using a modified 2D-spin-echo sequence with an integrated 2D-selective Transmit SENSE excitation module with a spiral *k*-space trajectory and slice selective refocusing. The experiments on the tomato were performed with a 3D-gradient echo sequence with the same 2D-selective Transmit SENSE module. The transmit-sensitivity calibration was done by acquiring conventional gradient echo images where the excitation was done with the different array elements successively, and the sensitivity maps were calculated using an adaptation of the algorithm described in [9] for the transmit case. The Transmit SENSE pulses had a spatial resolution of 32 x 32 points in the field of excitation (FOX) and were calculated in MATLAB (The MathWorks Inc., Natick, MA, USA) using the approach presented in [10].

Results: The results of our first in-vivo application of Transmit SENSE are presented in Figures 1 and 2. Figure 1a shows a conventional gradient echo scout-image of the rat head in which the brain was selected as a region of interest (ROI). Then, this ROI was selectively excited using single-channel excitation (Figure 1b, pulse length 14.42 ms) as well as Transmit SENSE with an acceleration factor of 2 (Figure 1c, pulse length 7.21 ms) and 2.67 (Figure 1c, pulse length 5.41 ms) and acquired (image matrix 128 x 128, FOX = FOV = 4 cm x 4 cm, TE=14.48 ms, TR=1500 ms). The definition of the excited area improves when moving from single-channel excitation to Transmit SENSE, due to the significantly shorter pulse lengths and the decreased sensitivity to off-resonance and B_0 inhomogeneity effects. Figure 2 shows the first results in a human subject. Transmit SENSE was used to excite a complex shaped ROI (see scout image in Figure 2a) in the frontal area of the brain. Figures 2b and 2c show that a good localization of the excitation can be achieved with an acceleration factor of 2 (Figure 2b, pulse length 6.87 ms) as well as 2.67 (Figure 2c, pulse length 5.16 ms) (image matrix 128 x 128, FOX = FOV = 22.5 cm x 22.5 cm, TE=14.6 ms, TR=1500 ms). However, some residual excitation remains in the skin areas of the head caused by off-resonance effects of the fat.

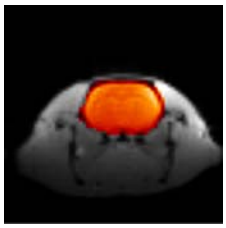
Figure 1a

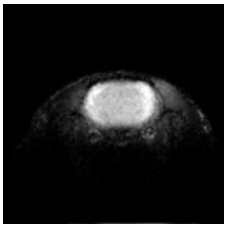
Figure 1b

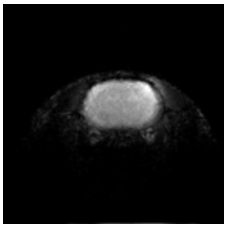
Figure 1c

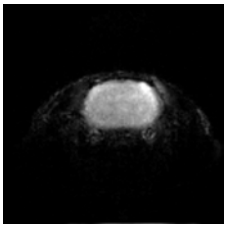
Figure 1c

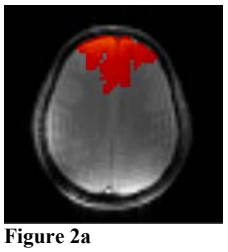
Figure 2a

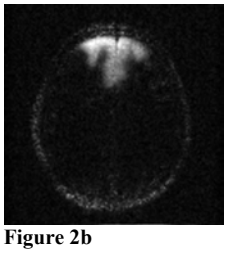
Figure 2b

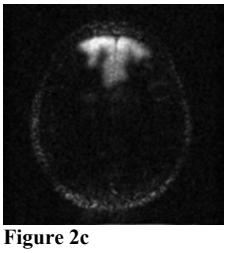
Figure 2c

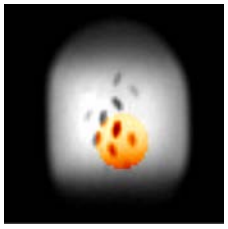
Figure 3a

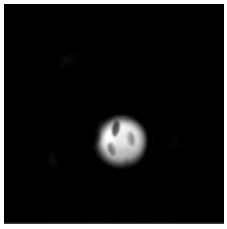
Figure 3b

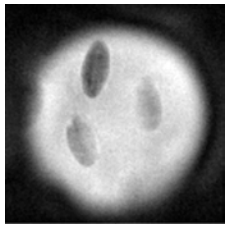
Figure 3c

Results of the experiments with the 3-element TX/RX-array in a biological sample are displayed in Figure 3. In Figure 3a a conventional gradient echo image of a cherry tomato was acquired and an ROI was selected. This ROI was excited afterwards using Transmit SENSE with an acceleration factor of 2. In combination with the high performance gradient system used in this experiment this lead to a pulse length of only 3.46 ms. The excited ROI was imaged using the 3D gradient echo sequence (image matrix 128 x 128, FOX = FOV = 2.8 cm x 2.8 cm, TE=2.27 ms, TR=100 ms) and the central plane for which the Transmit SENSE pulse had been calculated is shown in Figure 3b. The acquisition was also accelerated by a factor of 2 and the image was reconstructed using the GRAPPA technique [11]. Therefore, this was a first experiment of "Double Parallel Imaging" where the concept of Parallel Imaging was used both for transmission and reception. In Figure 3c the imaging FOV was reduced to the excited region of interest and a "zoomed" image was acquired (TE=2.87 ms, TR=30 ms, 20 averages). There are no significant fold-over artifacts due to the very good definition of the excited ROI. In this case the FOV was as small as 8 mm x 8 mm so that a very high inplane-resolution of 63 µm x 63 µm could be achieved with an image matrix of only 128 x 128 points whereas a matrix of at least 448 x 448 points would have been needed to achieve the same resolution in the full FOV. This means a reduction of a factor 3.5 in scan time using this technique of reduced-FOV imaging.

Discussion and Conclusions: In this work first in-vivo applications of Transmit SENSE are presented. It is shown that multi-channel localized excitation of previously defined ROIs can successfully be performed in a rat as well as on a human subject with very reasonable quality. However, in some cases there is still residual signal coming from locations with off-resonance spins (e.g. fatty tissue) or from small-scale B_0-inhomogeneities. This problem may be addressed by further reducing the pulse lengths or by incorporating main field maps in the calculation of the pulses, whereas the latter is limited by the intrinsic spatial resolution of the pulses. A further experiment in a biological sample using a novel TX/RX-array demonstrated the combination of transmit and receive Parallel Imaging and illustrates that very high spatial resolution images can be obtained with modest matrix sizes by reduced-FOV imaging of a Transmit SENSE-excited ROI. Further goals of this study will be the transfer of the technique to other body parts and other animals, using additional coil-setups, and to show in-vivo results of B_1-inhomogeneity compensation in addition to the presented localized excitation.

References: [1] U. Katscher et al., Magn. Reson. Med. 49:144-150 (2003); [2] Y. Zhu, Magn. Reson. Med. 51:775-764 (2004); [3] P. Ullmann et al., Magn. Reson. Med. 54:994-1001 (2005); [4] P. Ullmann et. al., Proc. ISMRM 2005, p.15; [5] Y. Zhu et al., Proc. ISMRM 2005, p.14; [6] P. Ullmann et al., Proc. ESMRMB 2005, 186; [7] S. Junge et al., Proc. ISMRM 2005, p. 918; [8] S. Junge et al., Proc. ISMRM 2004, p. 41; [9] M. Griswold et al. Proc. ISMRM 2002, p. 2410 [10] W. Grissom et al., Proc. ISMRM 2005, p. 19 ; [11] M. Griswold et al., Magn. Reson. Med. 47:1202-1210 (2002).