Dynamic Multi-Coil Shimming of the Human Brain at 7 Tesla

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INTRODUCTION: Magnetic field homogenization of the human brain (i.e. shimming) is a demanding task and satisfactory whole brain shimming is not possible with current shimming methods, especially at high magnetic B_0 fields.

A novel shimming technique for the human brain is presented in which basis fields are no longer based on spherical harmonic (SH) functions, but are generated by a set of individual, generic coils. After the introduction of the multi-coil (MC) approach [1], its application for shimming the mouse brain [2] and the prediction of the benefits for the human brain [3], here we present the theoretical design and first experimental results of dynamic MC (DMC) shimming of the human brain at 7 Tesla.

METHODS: Simulations based on the Biot-Savart law were used to derive a MC setup consisting of 4 rings of 12 circular coils (100 turns, diameter 5 cm) on an elliptical surface large enough to hold a human head (Fig. 1A). Shim fields over the whole brain or parts thereof can be generated with this setup through optimization of the 48 individual coil currents with a least-squares approach [1]. In its experimental realization the coils were mounted on the outside of an acrylic former (OD 23 cm/19 cm, Fig. 1B) and placed and operated inside an 8-channel Tx/Rx RF antenna (Fig 1C). A 10 cm gap between the two center rows of the MC array minimized interactions of the two systems. Custom-built amplifier electronics was used to drive the shim coils individually in the ±1 A range and allowed the fast application of the MC shim fields (<200 µs). DMC shimming was done on axial slices covering the whole brain and compared to static, whole brain zero-to-third order SH shimming and state-of-the-art zero-to-third order SH dynamic shim updating (SH-DSU)[4]. Experiments were carried out on a 7 Tesla human MR system and field maps were calculated from five gradient-echo images (field-of-view 210 x 210 x 120 mm^3, matrix 70 x 70 x 40) at variable echo time delay.

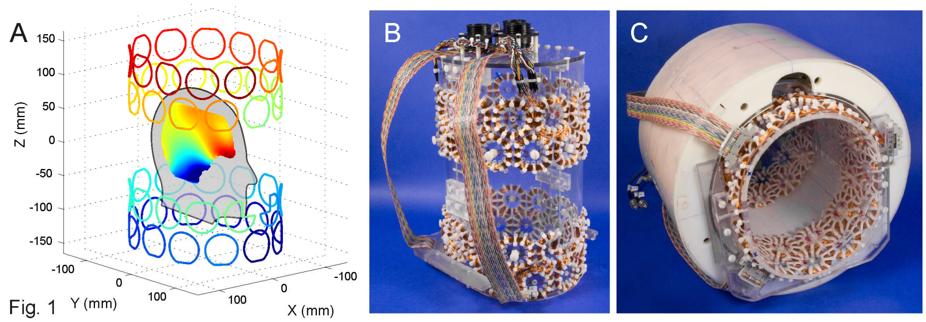

Fig. 1

RESULTS: A central axial slice (Fig. 2A) has been selected for the comparison of the compensation strategies of the magnetic field inhomogeneity typically encountered in the human brain at 7 Tesla (Fig. 2B). The strong and localized magnetic field patterns in the prefrontal cortex and the temporal lobes could not be synthesized with static SH field modeling (Fig. 2C) and major distortions remained after shimming (Fig. 2D). As expected, the complex field artifacts could be more adequately resembled with a dynamic SH approach (Fig. 2E), but considerable higher SH-order inhomogeneity remained over the entire brain even after state-of-the-art SH-DSU (Fig. 2F). Field modeling with the novel DMC method was not only capable of synthesizing a deeper and more localized field focus in the prefrontal cortex, but also allowed the simultaneous generation of the localized patterns in the temporal lobes and in the posterior part of the brain (Fig. 2G). Concomitantly, theoretical DMC shimming outperformed SH-DSU in the prefrontal cortex and over the rest of the brain (Fig. 2H). The magnetic field distribution after ***experimental*** DMC shimming (Fig. 2I) with the presented MC setup was in good agreement with the theoretical prediction (Fig. 2H) and showed superior field homogeneity than after SH-DSU.

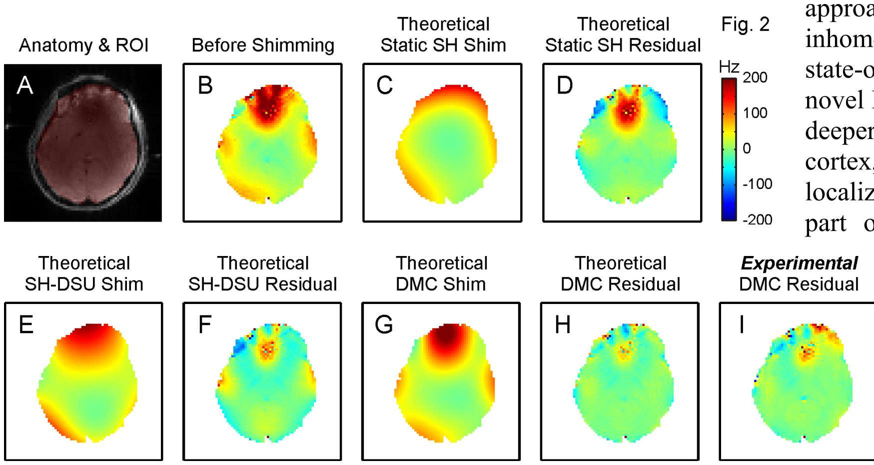

Fig. 2

DISCUSSION: Dynamic MC shimming of the human brain at 7 Tesla has been introduced. The method is by no means limited to axial slices and other slice orientations or differently shaped shim volumes are also possible. No eddy currents were observed with the presented MC setup and no pre-emphasis was necessary. The close congruence of theoretical predictions and experimental results once more proves the established framework of MC-based field modeling and the presented work bridges the gap between methodological MC developments in miniaturized setups [1,2] and their translation to address unsolved problems in human MR.

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