Integrated Parallel Reception, Excitation, and Shimming (iPRES)

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TARGET AUDIENCE: Anyone interested in MR engineering, high field systems, RF coils, parallel excitation and reception, or B_0 and B_1 shimming.

PURPOSE: Ever increasing static magnetic field (B_0) strengths have posed many technical challenges, most notably a higher B_0 field and RF field (B_1) inhomogeneity. Active shimming is the most widely used B_0 shimming method and typically employs spherical harmonic (SH) coils. In practice, however, SH shimming cannot effectively correct for high-order localized field distortions. Recently, Juchem et al. have proposed a multi-coil modeling and shimming method [1,2], in which a large number of small localized electrical coils is used to shape the B_0 field, thus achieving a better performance than SH shimming. However, it requires a separate set of shim coils adjacent to the RF coil array, which takes valuable space around the subject and also raises comfort and safety concerns for the subject. In addition, the electromagnetic interference between the RF and shim coil arrays (RF shielding) needs to be minimized at the cost of a reduced shimming performance [2]. To address these limitations, we propose a new general concept termed integrated parallel reception, excitation, and shimming (iPRES), based on a unified coil array. We outline the general concept based on a multiple-coil array and perform proof-of-concept experiments with a two-coil array to demonstrate its feasibility.

THEORY: The iPRES concept is based on a simple principle in electronics that both an RF and a direct current (DC) can coexist independently in the same circuit with no electromagnetic interference between each other. An implementation example of this concept is shown in Fig. 1. Its distinctness from a traditional parallel transmit/receive coil array [3] lies in that not only RF currents flow in each loop element, but DC currents circulate in the same loops as well. The DC mode is integrated into each coil element by using an appropriate circuit design, so that the B_0 field produced by the DC currents can be used for B_0 shimming. Such a unified coil system therefore has the capability to perform parallel excitation, reception, and B_0 shimming simultaneously to achieve a uniform B_1 field, accelerated parallel imaging, and a homogeneous B_0 field, respectively. Furthermore, multi-coil field modeling and shimming [1,2] has shown that the B_0 field shaping capability does not critically depend on the exact number, size, positioning, or geometry of the individual coils as long as a reasonably large number of coils is used (typically 24-48). Therefore, it is natural to expect that, in a unified coil system, a large number of coils working in the DC mode will provide an effective B_0 shimming alike.

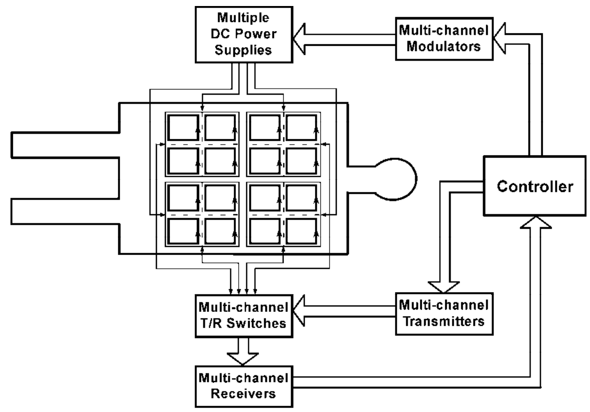

Fig. 1: Example of the iPRES concept: schematic diagram of a 16-channel unified coil system for cardiac imaging.

METHODS: A two-coil array made of a figure-8 and a single-loop surface coil (11×11 cm) was designed for concurrent RF excitation/reception and B_0 shimming. In Fig. 2, the addition of an inductor L_1 in conjunction with a DC power supply forms a closed loop and allows a DC current to circulate in the figure-8 pathway, thereby generating a B_0 field that can be used for B_0 shimming. Both coils were positioned, partially overlapped, in a coronal plane on top of a square water phantom containing a grid. A B_0 inhomogeneity was introduced in the phantom by placing a stack of 20 coins (US quarters) on top of the coils, resulting in a strong localized field distortion similar to those present in brain regions such as the inferior frontal cortex. The optimal DC currents to be applied in both coils were automatically determined in Matlab by minimizing the residual field between a weighted combination of two B_0 maps acquired with a DC current in each coil, but no coins, and a B_0 map acquired with the coins, but no DC currents.

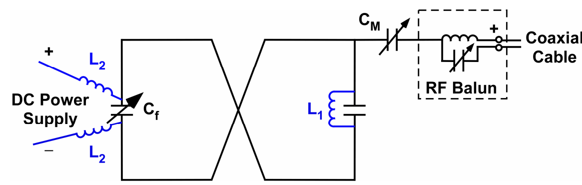

Fig. 2: Schematic circuit of the modified figure-8 coil for creating a DC mode. The inductors L_2 stop RF currents. The RF balun reduces RF coupling. C_f & C_M are tuning & matching capacitors.

RESULTS: Fig. 3 shows representative EPI images and B_0 maps in a 6×6 cm ROI acquired on a 3T scanner under three different conditions. First, an image was acquired without DC current, resulting in minimal geometric distortions (a). Second, a B_0 inhomogeneity was introduced by placing the coins, resulting in a strong localized nonlinear B_0 field distortion (d) and nonlinear geometric distortions (b). Third, individually optimized DC currents were applied in both coils to generate a shim field and compensate for the B_0 inhomogeneity introduced by the coins, resulting in a significant reduction of the B_0 inhomogeneity (e) and geometric distortions (c).

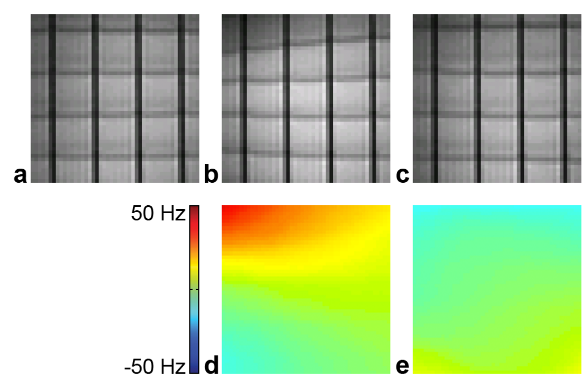

Fig. 3: EPI images (**a–c**) and B_0 maps (**d–e**) acquired with no coins, DC = 0 mA (**a**), with coins, DC = 0 mA (**b**,**d**), or with coins, DC = -278 mA (single-loop) and 280 mA (figure-8) (**c**,**e**).

DISCUSSION and CONCLUSION: These proof-of-concept experiments demonstrate the feasibility of the proposed iPRES concept. Although there are residual B_0 inhomogeneities and geometric distortions because our experiments were performed with only two coils, which offers a limited flexibility for B_0 shimming, it is expected that a more effective shimming can be achieved with a larger number of coils. The iPRES concept benefits from many potential advantages. First, by using multiple localized coils, it has the ability to achieve a more effective high-order shimming than SH shimming. Second, by eliminating the need to use separate coil arrays for excitation/reception and B_0 shimming, as in the multi-coil shimming method [1,2], it can simplify the scanner design, save valuable space within the magnet bore, avoid the RF shielding effect, and simultaneously maximize the performance of both the RF coil and the localized B_0 shimming, since the unified coil array can be in close proximity to the subject. Finally, a unified coil array that can perform parallel excitation and reception as well as B_0 and B_1 shimming concurrently will be particularly beneficial for ultra-high field MRI (7T and above), given its potential for simultaneously addressing two critical problems (B_0 and B_1 inhomogeneity).

REFERENCES: 1. Juchem C et al. Magnetic field modeling with a set of individual localized coils. J Magn Reson. 2010;204:281–289. 2. Juchem C et al. Dynamic multi-coil shimming of the human brain at 7 T. J Magn Reson. 2011;212:280–288. 3. Gräßl A et al. Design, evaluation and application of a modular 32 channel transmit/receive surface coil array for cardiac MRI at 7T. Proc. 20th ISMRM 2012;p 305. Work supported by NIH grants EB012586 and EB009483.