MRI using straight wires as spatial encoding coils

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Introduction: In conventional magnetic resonance imaging (MRI), spatial encoding of signals is performed using gradient coils that generate a spatially linearly increasing magnetic field and thus have a constant gradient. However, it has been shown in numerous studies that MRI can also be successfully performed with signal encoding coils that generate nonlinear magnetic fields [1-4]. In this study, we demonstrate that such imaging is possible with an extreme type of such coils, namely, straight wires that generate extremely nonlinear magnetic fields.

Methods: We recently proposed a new method for MRI using nonlinear encoding coils [5] in which the Fourier conjugate pair $\vec{k}$ and $\vec{r}$ is replaced by the pair $\vec{t}$ and $\vec{\omega}$. This change allows the use of the Fourier transform in the transformation of image signals from the time domain to the frequency domain. The obtained spectrum $\hat{S}(\vec{\omega})$ can then be converted into an image $\rho(\vec{r})$ using the relation:

$$\rho(\vec{r}) = \hat{S}(\vec{\omega}(\vec{r}))\left|\frac{\partial\vec{\omega}}{\partial\vec{r}}\right| \qquad \text{Eq. 1}$$

where $\vec{\omega}(\vec{r})$ is the transformation between frequency and spatial coordinates, which is an inherent property of the encoding coils, and $\left|\partial\vec{\omega}/\partial\vec{r}\right|$ is the Jacobian determinant of this transformation. This method was used in reconstruction of images acquired with three different types of simple encoding coils all build from straight wires, as sources of inhomogeneous magnetic field, in different arrangements: 2D nonsymmetric (Fig. 1A), 2D symmetric (Fig. 1B), and 3D nonsymmetric (Fig 1C). Experiments were performed with encoding coils in the *xy* plane at *z* = 0 using a spin-echo imaging sequence on a 2.35 T MRI system. Signal acquisition was performed at a BW 50 kHZ and a FOV 5 cm.

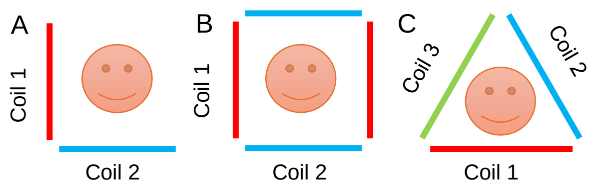

Fig. 1: Schematic of three different tested types of encoding coils arrangements.

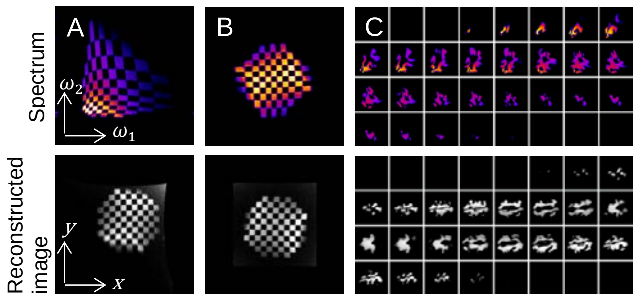

Fig. 2: Spectra and corresponding reconstructed images.

Results and discussion: All tests, i.e., 2D experiments on a checkerboard disc phantom with nonsymmetric (Fig. 2A) and symmetric (Fig. 2B) encoding coils, as well as a 3D simulation performed on a digital image of a walnut and encoding coils implemented with three wires arranged in a triangle (Fig. 2C), yielded reconstructed images that well depict the test phantoms, while their corresponding spectra have geometric and intensity distortions that were corrected in the reconstruction process using Eq. 1.

Conclusion: The results of the study may help advance "gradient" coil design towards freer geometries, higher magnetic field gradients or lower inductance and thus faster switching times.

References: [1] Hennig, MAGMA (2008). [2] Schultz, Magn. Reson. Med. (2010). [3] Stockmann, Magn. Reson. Med. (2010). [4] Wang, Magn. Reson. Med. (2016). [5] Tušar, Sci. Rep. (2024).