Traveling Wave MRI in a Vertical Bore 21.1-T System

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Introduction:

Traveling wave MRI relies on the propagation of temporally and spatially variant RF waves inside a scanner using a waveguide [1], namely the bore/shield of a scanner or a specially constructed metal enclosure. At 7 T, only the lowest TE_{11} mode of the cylindrical waveguide can propagate in a hollow bore due to stringent cut-off wavelength requirements [1,2]. However, with the higher fields of pre-clinical animal and vertical magnets, the typical diameter of the open bore is usually small compared to the free-space critical wavelength of the propagating mode in such a waveguide. Under these conditions, other modes of a cylindrical waveguide (hybrid, TM as well as higher order TE modes) are only allowed through the use of high permittivity dielectrics [3,4].

In this study, a novel partially filled cylindrical dielectric waveguide capable of operating in the traveling wave regime is demonstrated in a vertical 21.1-T ultra-wide bore magnet. The feasibility of remote imaging for both phantom and tissue samples is displayed for a simple transceive loop coil traveling wave implementation.

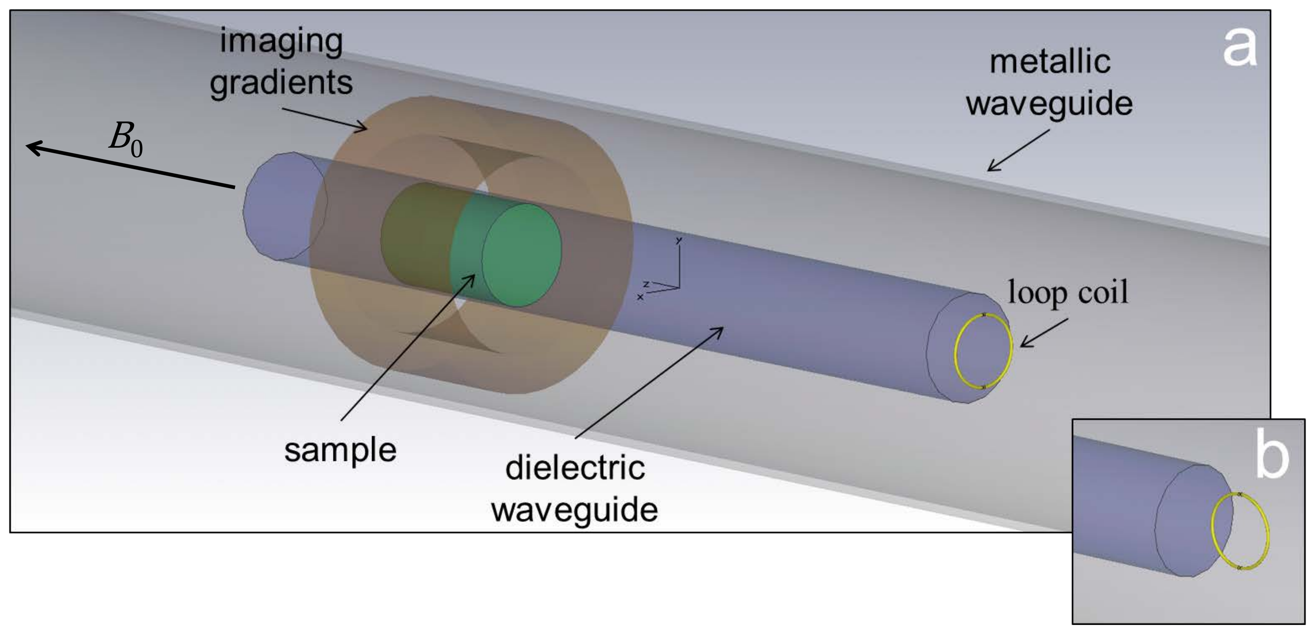


Fig. 1: Simplified schematic of a cylindrical waveguide for 21.1 T for (a) parallel and (b) orthogonal coil orientations. Loop coil diameter = 2.4 cm, dielectric waveguide = 3.5-cm OD x 34-cm length, metallic waveguide = 5.5-cm OD, gradients = 6.3-cm ID, distance from coil to sample = 21-24 cm

Materials & Methods:

- Vertical 21.1 T (900-MHz ^{1}H Larmor freq, λ = 33 cm)
- Available diameter: 6.3-cm ID imaging gradients
- Critical wavelength λ_{cr} = 18 cm for the first available TE_{11} waveguide mode
- Aqueous samples provide the high permittivity required to modify the cut-off requirements
- Partially filled concentric waveguide (see Fig. 1)
  - Inner waveguide: dielectric composed of deionized water (ε_r = 80) with 3.5-cm OD and 33-cm length
  - Outer waveguide: hollow copper waveguide with 5.5-cm OD and 33-cm length
  - Under these conditions, multiple propagation modes are supported with λ_{cr} > 4.4 cm

Electromagnetic Simulations:

- A finite element method (COMSOL Multiphysics) was employed for the screened dielectric waveguide: ε_r = 80, σ = 5x10^{-5} S/m

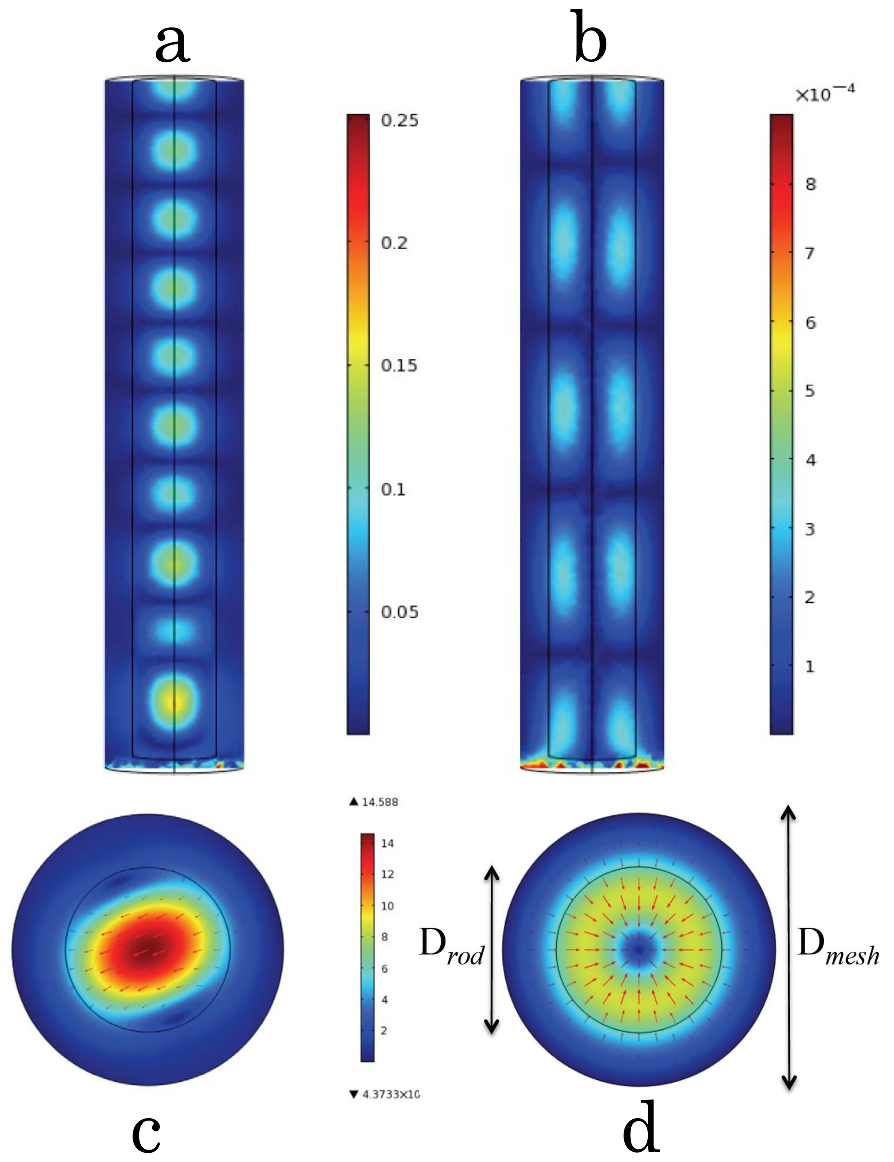
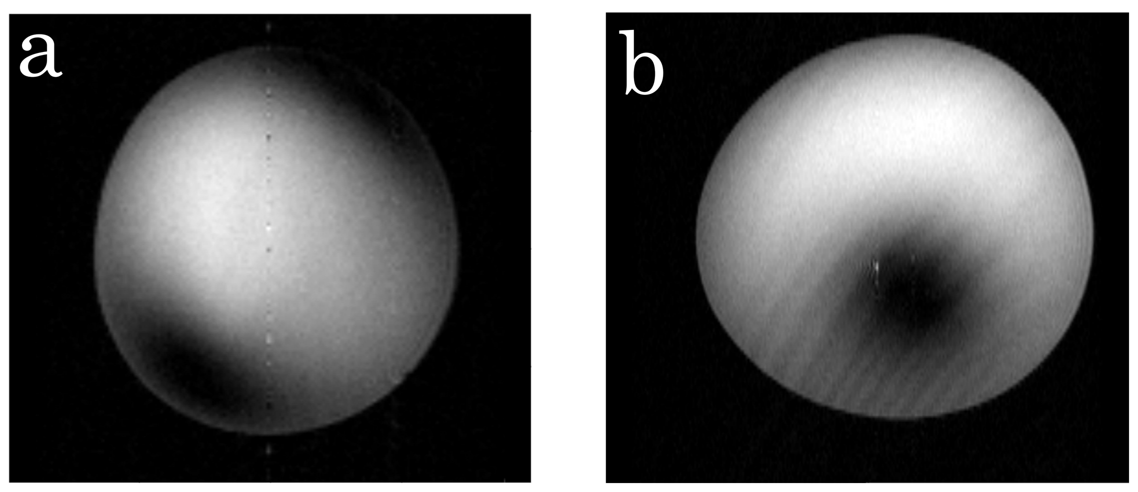


Fig. 2: B_1 field maps in a partially filled dielectric waveguide. (a,c) TE_{11} mode and (b,d) TE_{01} through coronal and axial slices, respectively. D_{rod} corresponds to the dielectric waveguide diameter (3.5 cm), and D_{mesh} is the diameter of the metallic waveguide (5.5 cm).

Results:

- Mode selection can be accomplished by altering coil orientation with respect to B_0, *i.e.* either orthogonal or parallel B_1 (see Fig.1)
- The orthogonal loop coil (Fig. 1b) results in images exhibiting a TE_{11}-like mode (Figs. 3a and 4a)
- The parallel loop coil (Fig. 1a) results in images exhibiting a TE_{01}-like mode (Figs. 3b and 4b)
- Compared to a 900-MHz birdcage coil (see Fig. 4c), the implemented waveguide technique provides an improved longitudinal coverage that is limited only by imaging gradient linearity



SNR = 43 *SNR* = 44

Fig. 3: Axial images from multislice 2D GRE datasets for the 3.5-cm deionized water waveguide: TE/TR = 5/500 ms, res. = 312x312 μm, FOV = 4x4 cm, 1-mm slice thickness. (a) TE_{11} mode acquired with the orthogonal loop; (b) TE_{01} mode acquired with the parallel loop. The signal-to-noise ratio (SNR) was computed over the entire cylinder for this slice, including the nulls.

- To show the feasibility of tissue imaging, high resolution 3D datasets of an *ex vivo* preserved mouse head immersed in 0.9% saline were acquired (Fig. 5).

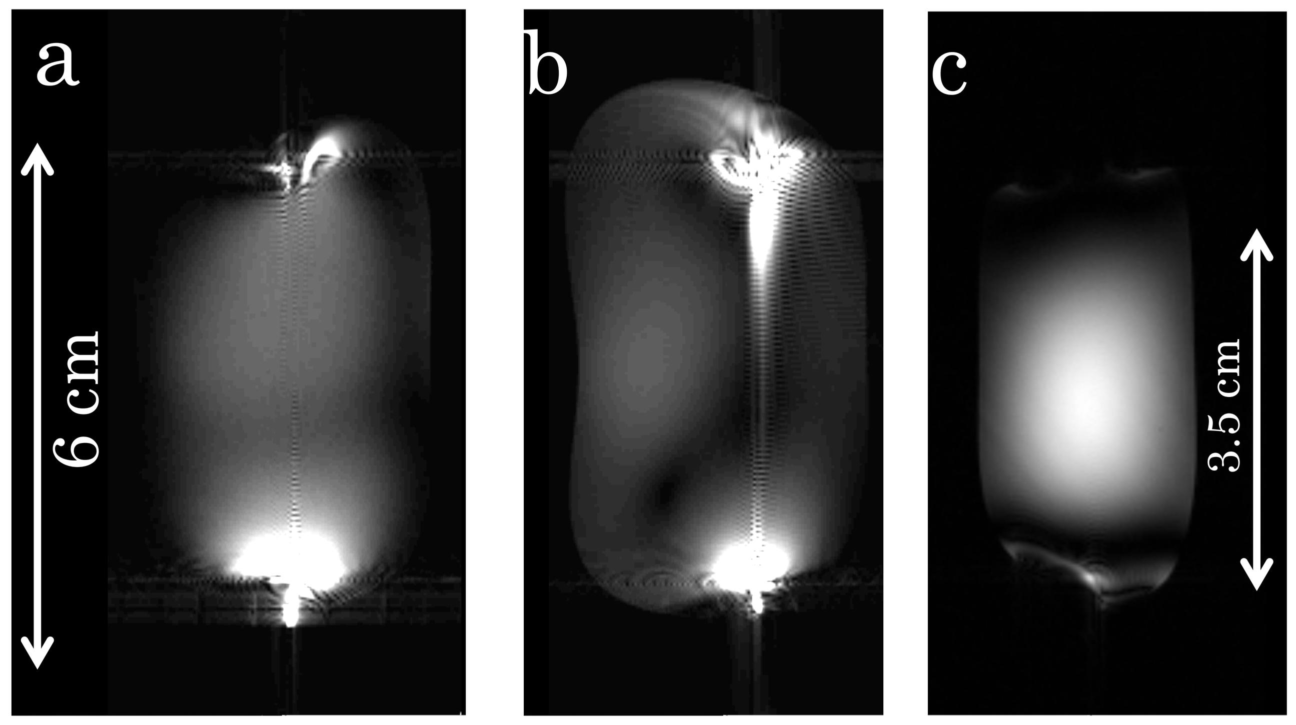


Fig. 4: Coronal images from multislice 2D GRE datasets for the 3.5 cm deionized water waveguide: TE/TR = 5/500 ms, res.=312x312 μm, FOV = 8x4 cm, 1-mm slice. (a) TE_{11} mode acquired with orthogonal loop; (b) TE_{01} mode acquired with parallel loop; (c) Birdcage coil loaded with a polyethylene glycol sample.

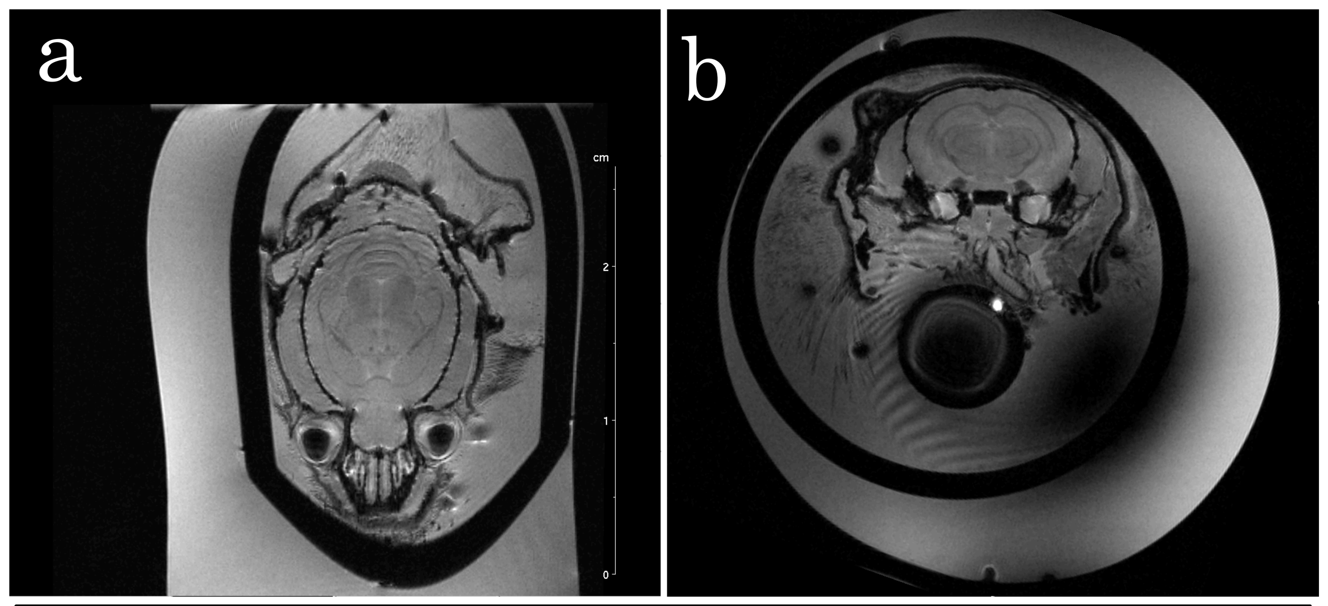


Fig. 5: (a) Coronal and (b) axial images of a preserved mouse head from a 3D GRE dataset: TE/TR=5/125 ms, iso. res.=100 μm, FOV = 3.5x3.5x3.5 cm. Data was acquired with the parallel loop coil. Note TE_{01} characteristic null in (b).

Conclusions & Discussion:

- With the appropriate waveguide dielectric/diameter combination, traveling wave MRI can be achieved in ultra-high field vertical widebore systems.
- Mode selection was achieved via manipulation of waveguide coupling with different RF configurations, showing that non-TE_{11} mode propagation is possible.
- RF simulations corroborate observed mode structures from MR images. However, in practice there exist mode asymmetries as well as hybrid HE_{nm} modes.
- With increases in B_0 field strength for clinical and pre-clinical systems, the impact of high dielectric materials for traveling wave MRI can become more significant.

References & Acknowledgements:

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