Hybrid RF Coils for Inner Ear Imaging at 7 T MR

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INTRODUCTION

Previous studies of the small anatomical images such as semicircular canal, cochlea, vestibule, and so forth for inner ear organs were performed in 1.5 T and 3 T MR scanner [1,2]. Nevertheless, these inner ear imaging has been limited due to the mainly small size of volume and low spatial resolution. To improve MR image sensitivity in the specific organ such as facial nerve, vestibulocochlear nerve, endolymphatic & perilymphatic space, labyrinthine artery, ultra-high field (UHF) MRI environment has to be offered. However, design of optimal radiofrequency (RF) coil and their RF circuitries for integrating into the UHF MR system are encountered as additional challenges. The purpose of this study was to develop the special RF coil for inner ear imaging at 7 T. The proposed hybrid RF coils [3] was designed by 8-channel transmit/receive (Tx/Rx) coil and dual 4-channel Rx-only coils, which is simultaneously allow improving the signal-to-noise ratio (SNR). The visualization of the inner ear imaging as well as inner ear structure at 7 T was implemented with developed hybrid RF coils.

MATERIALS AND METHODS

All experiments were performed on a 7 T MR whole body scanner (Magnetom, Siemens Healthcare, Erlangen, Germany) equipped with superconducting magnet (Magnex Magnet Technology, Oxford, UK). The hybrid RF coils (Fig. 1c) are comprised of two parts such as 8-channel Tx/Rx coil (Fig. 1a), dual 4-channel Rx-only coil (Fig. 1b), and their RF circuitry (Fig. 1d-f) were designed. The Tx power in the hybrid RF coils was driven by the 8-way power divider (PD) using one 2-ways and two 4-ways lumped element Wilkinson PD for supplying the balanced RF power energy into the 8-channel Tx/Rx coil (Fig. 1a). The active decoupling circuit (Fig. 2a) in 4-channel Rx-coil is based on lattics balun and was implemented for mutual decoupling when the 8-channel Tx/Rx coil is operating in the Tx-mode. To measure the decoupling efficiency, a single element within the 4-channel Rx-coils was measured for S_{12} measure by a pair of uncoupled pick-up probe while hooked up to the preamplifiers. In nominal case, which is no forward biased state, S_{12} was measured -16 dB (Fig. 2b). However, in forward biased state (i.e., transmitting), S_{12} was measured as -46 dB. The 4-channel Rx-coil was 30 dB isolated from 8-channel Tx mode due to the active detuning. MRI in-vivo scans were performed without gadolinium injection a 7 T scanner using designed hybrid RF coils. The following sequence, covering the internal auditory canal (IAC) of human brain was acquired: a spatial resolution 0.4 mm (isotropic) three-dimensional (3-D) T1-weighted volumetric interpolated breath-hold examination (VIBE) protocol (TR = 20 ms, TE= 2.78 ms, $\alpha = 6°$, field of view = 200 × 200 mm, voxel size = 0.4 × 0.4 × 0.4 mm, slice thickness = 0.45 mm, base resolution = 448, bandwidth = 200 Hz). Time-of-flight (TOF) angiography (TR = 15 ms, TE= 4.85 ms, $\alpha = 17°$, FOV= 135× 180, matrix size = 768 × 768, pixel bandwidth= 90 Hz, acquisition time = 7 min 12 s, voxel size = 0.23 mm × 0.23 mm, slice thickness = 0.36 mm) was also implemented for investigating the phenomenon of flow-related enhanced spins in the specific vestibulocochlear nerve pathway.

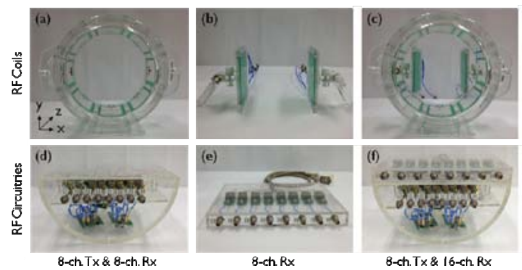

Fig 1: Hybrid RF coils using (a-i) 8-channel Tx/Rx volume coil and (b-i) dual 4-channel Rx-only coil and their RF circuitry

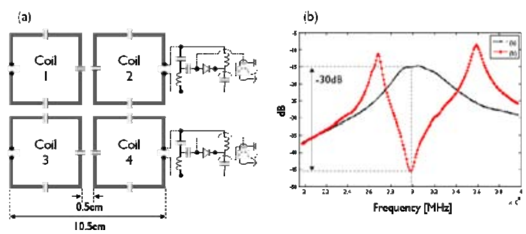

Fig 2: Active decoupling circuit in 4-channel Rx-only coil was implemented to decrease significant current flow generated by 8-channel volume Tx/Rx coil

RESULTS

All outputs of the receive coils, 8-channel Rx-coil (i.e., P1 to P8 in Fig. 3a) and dual 4-channel Rx-coil (i.e. R9 to R16 in Fig. 3a), totally 16 channel Rx-coil, were connected to low input impedance preamplifiers [4]. The 3-D high-resolution MR images were derived from the 2-D inner ear image through the VIBE imaging sequence (Fig. 3). The in-vivo normal anatomy image of the membranous labyrinth was obtained with the hybrid RF coils. The 7 T inner ear image reveals the detailed structure of the entire inner ear cochlear and clearly depicts the three semicircular canals with vestibulo-cochlear nerve of a single healthy volunteer. The visualization of anterior inferior cerebellar artery with labyrinthin artery, in the inner ear was also demonstrated from angiographic protocol (Fig. 4). Various angles at an interval of 0.3mm were involved for a detailed investigation of the vestibulocochlear nerve track.

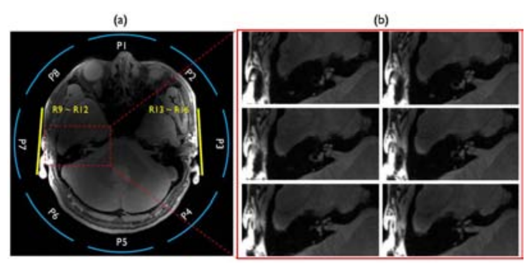

Fig 3: (a) 2-D inner ear axial images using VIBE protocol from a healthy volunteer and (b) enlarged views for inner ear

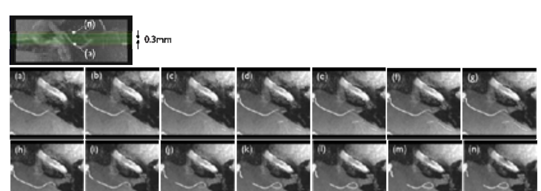

Fig 4: The visualization of anterior inferior cerebellar artery in the inner ear

CONCLUSIONS AND DISCUSSIONS

We expect that developments from a new perspective of inner ear imaging using a 7 T modality and new RF coil will show further improved image sensitivity and thus allow ultra-structural MRI.

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