High-resolution in vivo MR imaging of the human hippocampus at 7 Tesla

Z-H. Cho[1], K. Kim[1], Y-B. Kim[1], K. T. Bae[2], and C-H. Moon[2]

[1]Neuroscience Research Institute, Gachon University of Medicine and Science, Incheon, Korea, Republic of, [2]Department of Radiology, University of Pittsburgh, Pittsburgh, PA, United States

[Introduction] Volumetric atrophy of the hippocampus is associated with a wide range of neurodegenerative diseases (ND), such as Alzheimer's disease (AD), and has been thoroughly evaluated at 1.5 or 3 T magnetic field MR imaging [1,2]. Neuronal deaths precede atrophy of whole hippocampus and affect its subdivisions regionally at different rates [3-5]. Visualization of the detailed internal structures of the hippocampus relative to the early pathologic changes and various disease patterns has already been studied [6-8]. Some of the hippocampus layer structures are sensitive to early changes in AD and may be used as an early disease biomarker. For example, dominant cell losses at the CA1 (cornu ammonis) layer were observed in hippocampal sclerosis [3] and AD [5]. Neuron cell death in AD was also strongly associated with nonheme iron deposit (or amyloid plaques) [9-13]. As a result, the MRI signal intensity profile from CA1 to CA4 is expected to deviate from normal [8]. Capillary/arteriole density change in AD hippocampus can affect the T2*-weighted MR signal at a high field. Consequently, this may be detected and used as a secondary imaging biomarker [14]. The hippocampus, which is located deep in the brain, is a compact, complex structure and consists of several components. In vivo, hippocampus imaging with conventional MR imaging is challenging because detailed visualization of its anatomy requires a resolution of 100 – 500 μm thick sub-layers. These layers are subjected to low tissue contrast, signal-to-noise ratio (SNR), and high sensitivity to motion artifact. Recent literature concerning in vivo MR imaging of the brain cortex at 7 T proposed that hippocampus layer structures may be discernible with imaging at ~200 μm pixel resolution [15]. *Thus, the purpose of our study was to demonstrate the feasibility of high resolution in vivo 7 T MR imaging of the detailed layers of the hippocampus, which may be used as a biomarker for the detection of early stage ND.*

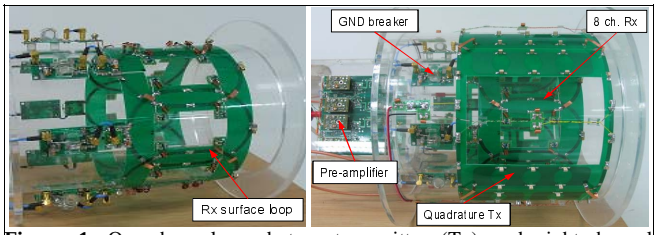

Figure 1. One-channel quadrature transmitter (Tx) and eight-channel receiver coils (Rx). (Left panel) Eight-channel Rx surface coils. (Right panel) Combined Tx and Rx coils.

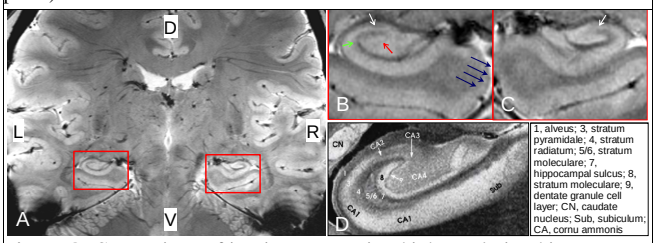

Figure 2. Comparison of in vivo vs. ex vivo high-resolution hippocampus MR anatomy image. A, Oblique coronal T2*-weighted GRE MR image of the hippocampus. No image post-processing was necessary or used. B and C, Magnified hippocampal images in left and right from red ROIs in A. D, Ex vitro hippocampus MR image at 9.4 T (Fatterpekar et al.[8]). The pixel-resolution is 78×78×500 μm and 100 averages (~14 hrs 17 minutes). Abbreviation - L, left; R, right; D, dorsal; V, ventricle.

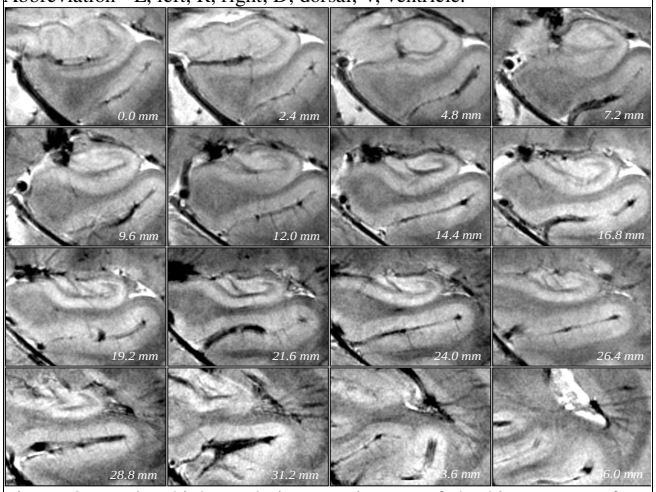

Figure 3. In vivo high resolution MR images of the hippocampus from head to tail. The right bottom numbering is for relative slice position from the first image; gap between slices is 2.4 mm.

[Methods] All MR imaging was performed on 7 T human scanner magnet (Siemens Medical system, Iselin, NJ) using a high-sensitive eight-channel surface Rx coil (diameter = 210 mm, height = 140 mm) combined with one-channel dual quadrature Tx volume coil (diameter = 300 mm, height = 180 mm) (see Fig. 1). Two male normal volunteers were scanned. Foam pads were inserted into two lateral sides of the head to immobilize the head within the coil cage. Magnetic field homogeneity shimming was conducted for the whole brain region. To reduce partial volume averaging, MR imaging plane was conducted in the oblique coronal plane, parallel to the long axis of the brain stem, approximately orthogonal to the long axis of the hippocampus [16]. The slice position for hippocampus imaging was based on a low resolution FLASH (TR/TE = 8.6/4.0 ms; matrix = 460×512; FOV = 250×250 mm; sagittal slice). For high-resolution hippocampus T2*-weighted anatomy imaging, the oblique coronal multi-slice gradient echo (GRE) acquisitions were performed with TE 17.8 ms, TR 750 ms, one average, flip angle 30°, bandwidth 30 kHz, matrix 896×1024, thickness 2 mm (with inter-slice gap 0.4 mm), 15-19 slices from anterior to posterior, and FOV 201×230 mm (i.e. in-plane resolution = 224×225 μm) and flow compensation on all imaging gradients. Each scan was approximately 12 minutes. The analysis ROIs were chosen to cover the fimbria to entorhinal regions of the left and right hippocampus. Structures of the hippocampus depicted in our in vivo MR imaging were evaluated with previously published ex vivo MR imaging anatomy of the hippocampus [8].

[Results and Discussion] Brain MR images generated with the eight-channel rf coil resulted in superb image quality, including high SNR in deep brain areas and the hippocampus. No specific rf pulse (e.g., adiabatic rf pulse) or post-processing was required to obtain homogeneous central image density variation (see Fig. 2A). In both volunteers, we were able to delineate hippocampus structures at high spatial and contrast resolution; such as the fimbria, dentate gyrus, cornu ammonis, subiculum, parahippocampal gyrus, and entorhinal area (see Fig. 2B and C). It may be difficult to delineate several layers in stratum and the dentate granule cell layer due to a low contrast-to-noise ratio (CNR) (see green and red arrows in Fig. 2B and 4-7 and 9 in D) at this resolution and one averaging. However from our MR images, we were able to identify layer structures in the entorhinal region (see black arrows in Fig. 2B). The CA2 region appears darker than the CA1, CA3 and CA4 regions (see white arrows in Fig. 2B and C), suggestive of increased cell density in this region [8]. Within a 15-minute scan time in vivo, the hippocampus can be imaged at any desired imaging plane and orientation to delineate the full 3D extent of the hippocampus (Fig. 3). The CNR can be improved further by use of thinner slices and increased averaging, or phase imaging. Our on-going research includes the optimization of MR parameters and hippocampus imaging of AD patients. In conclusion, we confirmed the feasibility of high-resolution in vivo hippocampus MR imaging to resolve hippocampal subdivisions and layer structures at 7 T. More cases and analysis will be presented at the meeting.

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