SELECTION OF COILS, SEQUENCES AND SCAN PARAMETERS FOR NON-HUMAN PRIMATE BRAIN IMAGING

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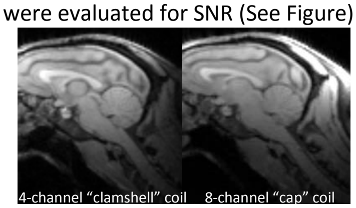
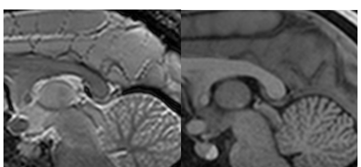
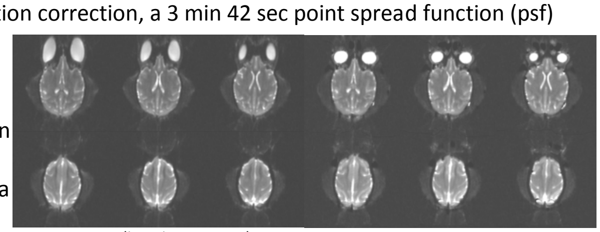
Purpose: To review the selection of RF coils, pulse sequence and scan parameters for structural and functional brain imaging of non-human primates (NHPs); to demonstrate that the small size of the NHP brain, desire for high spatial resolution, and ability to scan for longer durations without bulk motion, leads to parameter selections that are not commonly used in human brain imaging; to reveal unique characteristics of NHP brain imaging that provide opportunities for protocol optimization that are not practical, or not available, for human brain imaging protocols.

Outline of Content: Study considerations: The study was approved by the Institutional Animal Care and Use Committee (IACUC). The scanning protocol was developed on a 3T Trio Tim MRI System running VB17A software (Siemens Healthcare, Inc. Erlangen, Germany) for evaluation of white matter development in Rhesus Macaques, with typical adult brain size 60 mm R/L, 90 mm A/P, and 50 mm H/F. To comply with anesthesia time limits, the calculated scan time was mandated to not exceed one-hour. NHP positioning: For brain imaging, the NHP was placed head first and prone in the sphinx position (head is turned up with eyes looking done the magnet bore), such that axial brain sections were acquired by specifying the coronal orientation. We'll refer to the collected images as axial, with anterior/posterior (A/P) and right/left (R/L) directions in the plane of the slice, as with human brain imaging. Selection of RF coil: A custom 8-channel cap coil (S/N: P-H08LE-030-01371-001 V01, Rapid MR Intl., LLC, Columbus, OH) and 4-channel clamshell coil (S/N: P-H04LE-030-01295-001, Rapid MR Intl., LLC Columbus, OH) were evaluated for SNR (See Figure) and uniformity of sensitivity. The 8-channel coil provided up to 35% higher SNR, based on values taken on a center vertical line through the brain on the sagittal images, and within each axial slice it provided more uniform SNR. Selection of spatial resolution: Previous NHP T1 and T2 weighted imaging using the 32-channel human brain imaging coil was routinely done with 0.7 mm isotropic spatial resolution (voxel size). Both the 8-channel and 4-channel coils provided higher SNR than the 32-channel coil. Thus, all T1 and T2 weighted imaging was done with smaller, 0.6 mm, isotropic voxel size. For DTI and BOLD EPI, test images with diffusion maps were acquired with 0.8 mm through 1.8 mm isotropic voxel size, and 1.2 mm isotropic voxel size was selected for the final protocol as having the best balance between SNR and voxel size. In EPI-based sequences, the pixel bandwidth (Hz/Px) was selected to minimize the echo spacing, which minimized the data acquisition time per slice. In human brain imaging, the echo spacing for EPI-based sequences is in the range 0.45 to 0.55 ms for a 2.0 mm voxel size; however, for the 1.2 mm voxel size in NHP imaging, a longer echo spacing in the range 0.92 to 0.94 ms is required. The longer echo spacing reflects the longer gradient duration required to achieve the higher k-space frequency for a 1.2 mm voxel size. In the EPI based acquisitions, the thin 1.2 mm slice thickness was enabled by increasing the RF pulse duration from 2560 to 5120 ms. T2 sequence selections: With 3D acquisition, use of sagittal slice orientation prevented wraparound of signal from the neck region into the brain, which occurred with axial slice acquisition due to imperfect RF pulse profiles. The Siemens' 3D T2 sequence (tse_vfl) produced very high contrast T2-weighted images. Two striking features of the images were 1. thin dark lines bordering all bright CSF spaces, due to Gibbs artifact and zero fill interpolation, 2. very dark blood vessels, due to blood susceptibility (See Figure). Testing established that this 3D T2 sequence was extremely susceptible to B0 inhomogeneity, more so than the BOLD EPI scan. T1 sequence selections: 0.6 mm isotropic voxel size was easily obtained with human brain imaging parameters (TI 1100 ms, TR 2500 ms, TE 2.66 ms, FA: 7 deg) using the 3D IR-prepped turbo-FLASH sequence (tfl) sequence, requiring only reduction of FOV to 154 mm, with 256 resolution in both readout and frequency directions. Sagittal slice orientation was used to match the T2 sequence. DTI sequence selections: The sequence is an EPI-based double spin-echo diffusion sequence provided by Freiburg University (mz_ep2d_diff_free, [1]). FOV was set to 120 mm, with 100 frequency resolution (for 1.2 mm voxel size), bandwidth 1220 Hz/Px, R/L frequency encoding and 5/8 Fourier encoding, to yield an echo spacing of 0.92 mm and minimum TE of 95 ms. Consistent with MR sampling theory, smaller FOV with less frequency resolution (e.g. 96 mm with 80 base resolution) did not change the optimal bandwidth or echo spacing. For distortion correction, a 3 min 42 sec point spread function (psf) calibration scan was implemented with the same acquisition parameters as in the diffusion sequence. With the anesthetized NHP, there is no bulk motion and the psf calibration provides excellent distortion correction (see Figure), and a 17 min 23 sec DTI scan was used to acquire 128 diffusion directions. The Siemens' advanced diffusion DTI sequence (ep2d-advdiff-511C, [2]), which did not provide the psf based distortion correction, was also evaluated. BOLD EPI sequence selections: Resting state EPI using a standard EPI sequence required a long TR of 4310 ms due to the long echo spacing (0.92 ms) dictated by the 1.2 mm voxel size, for 48 slices, TE 22 ms and 5/8 Fourier encoding. To reduce TR, a multi-band EPI sequence (cmrr_mbep2d_bold, [3]) with 140 repetitions was implemented using slice acceleration factor 2, leading to TR 2310 ms, with echo spacing 0.93 ms, 1.2 mm voxel size, 1220 Hz/Px bandwidth, 48 slices, TE 22 ms and 5/8 Fourier encoding.


4-channel "clamshell" coil 8-channel "cap" coil


T2: 0.6 mm isotropic T1: 0.6 mm isotropic


DTI: not distortion corrected DTI: distortion corrected

Summary: RF coils and scan parameters selected for non-human primate (NHP) brain imaging (specifically adult Rhesus Macaques) are significantly different from those selected for human brain imaging, due to the smaller size of the NHP head and the use of anesthesia with the NHP which eliminates bulk head motion. The abstract describes custom RF coils, unique pulse sequences (generally available through research agreements with the developers) and uncommon parameter selections to acquire NHP brain images with high spatial resolution, tissue contrast, and SNR.

References: [1] Zaitsev M. Freiburg Univ. C2P Package for Distortion Correction DTI, Ver. 2.6.6, July 1, 2011. [2] Feiweier T. WIP package for advanced EPI diffusion, Ver. 511C, Dec 2010. [3] Yacoub, E. Univ. Minnesota C2P Package for Multi-band EPI, Rel. 006b, June 21, 2012.