Routine high resolution MRI in small animals at 9.4 Tesla using a cryogenic quadrature transceive RF probe

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INTRODUCTION In recent reports, the advantages of cryogenic radio frequency (RF) probes compared to room-temperature coils for MR imaging have been investigated both theoretically and experimentally at different magnetic field strengths [1-3]. It was found that cooling of RF coil and preamplifier leads to a significant increase in sensitivity, because sample noise and thermal noise are of comparable order in small animal MRI. This gain in sensitivity can be traded either for higher spatial resolution or increased acquisition speed. In this work two RF probes designed for high resolution imaging of the mouse brain were compared. A cryogenic quadrature transceive coil and a room temperature quadrature receive only coil. Both coil setups are commercially available and suitable for routine MR imaging. In particular, the sensitivity gain under in vivo conditions shall be estimated. For this purpose, spin echo and gradient echo images were acquired in six mice. In addition, high resolution images of the cerebellum were recorded in the same animal using both the cryogenic and the room temperature RF probe.

METHODS All experiments were carried out on a Bruker BioSpec 94/30 (Bruker BioSpin MRI, Ettlingen, Germany) small animal MR system operating at 400 MHz. Two RF coil setups were investigated with respect to signal-to-noise ratio (SNR): a) A curved rectangular room temperature (RT: 293K) quadrature receive only surface coil (side-by-side overlapping coils, total size: 27x17mm [arc length x length]) in combination with a linear polarized bird-cage resonator (inner diameter: 72 mm) for transmission. The setup was provided by Bruker BioSpin MRI, Ettlingen, Germany. b) A transceive cryogenic quadrature RF surface probe (CRP) with similar coil geometry as the RT surface coil (total size: 27x20mm) operating below 30K with an integrated cooled preamplifier (operating at 77K). The cryogenic RF probe with a flexible design [4] and the appropriate Cryo-platform to ensure constant cooling were provided by Bruker BioSpin AG, Fällanden, Switzerland. The amplitude of the excitation B1-field of the transceive CRP were adjusted using a coronal slice of 1mm thickness positioned 2mm from the head outer surface [5].

In vivo experiments were carried out in strict adherence with the Swiss law for animal protection. C57/Bl6 mice were anesthetized using 1.5% isoflurane in an oxygen/air (20% / 80%) mixture. Animals were intubated, artificially ventilated and paralyzed using the neuromuscular blocking agent Pancuronium bromide (1-1.5 mg/kg dose). To ensure reproducible positioning, the animals were stereotactically fixated on the same animal support for both RT and CRP measurements. In total, 6 different animals were examined: four using CRP only, one using RT only and one animal using both coil setups.

For SNR comparisons both spin echo (SE) and gradient echo (GE) sequences were applied using the following parameters: FOV: 20x20mm; 15 slices; acquisition matrix: 384x384; voxel dimension: 52x52x500µm^3; spin echo (RARE): TE/TEeff/TR: 12.9/38.6/4200ms; RARE factor: 8; scan time: 3min 22sec; gradient echo (FLASH): TE/TR: 8.0/343.4ms, scan time: 2min 12sec. SNR values were derived from mid-sagittal images using different regions of interest (ROI) with increasing distance to the head outer surface (Fig. 1). In addition to careful positioning of the animals, the position of the coil center was verified on the sagittal images. Partial volume effects and large signal changes were avoided by selecting homogeneous brain areas. Noise was estimated from the same scan, but from a separate ROI (Fig. 1).

High resolution structural imaging of the same animal was performed using both the RT and the CRP coil setup. Data were acquired using T2*-weighted GE sequences (FLASH: FOV: 20x20mm; 11 slices; acquisition matrix: 400x400; pixel dimension: 50x50µm^2; TE/TR: 18/400ms; averages: 4; scan time: 10min 40sec) with two different slice thicknesses of 500µm and 170µm, respectively. Finally, the performance of the CRP coil was demonstrated by comparing in vivo MR images with histological analyses: FLASH: FOV: 18x18mm; 9 slices; acquisition matrix: 600x600; voxel dimension: 30x30x300µm^3; TE/TR: 12/400ms; averages: 8; scan time: 32min). A histological cross-section of the corresponding brain section was prepared for identification of brain structures detected in vivo.

RESULTS Excellent image quality was achieved using the cryogenic RF probe for both SE and GE sequences (Fig. 1). Comparing CRP versus RT an average gain in SNR of 2.5 (range: 2.4-2.8(GE) and 2.3-2.7(SE)) over all ROIs (excluding the ROI close to the coil) was found for both GE and SE sequences (Fig. 1c). The accuracy in positioning of the mouse head can be deduced from the small error bars in Fig. 1 and from the slice angulations (mean: 0.18°; range: -5° - +5°) around the feet-head axis. Superior image quality in terms of SNR was achieved in high resolution imaging of the cerebellum using CRP as compared to RT data acquired with identical imaging parameters (Fig. 2). Furthermore, the cryogenic probe provided at very high spatial resolution still sufficient SNR to resolve micro-structures of the cerebellum in acquisition times of 30 min or less (compare Fig. 2b and 2e).

DISCUSSION The comparison of a cryogenic transceive quadrature RF probe with a quadrature receive only coil revealed SNR gains of 2.5 on average for in vivo imaging of the mouse brain for both spin echo and gradient echo sequences. Deviations from this average value were found for areas close to the coil, where the transmit field of the CRP is increased due to the proximity of the coil conductors. The increased SNR in combination with a stable animal preparation enables high resolution structural imaging (voxel dimensions of 50x50x170µm^3) allowing the identification of fine anatomical structures such as white matter, granular layer, Purkinje cell layer and molecular layer in the murine cerebellum. High resolution images were recorded in acquisition times ranging from 10 to 30min showing suitability of this flexible cryogenic RF probe for routine high quality imaging studies of the mouse brain.

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REFERENCES [1] Doty FD. et al. NMR Biomed 2007 (20):304-25; **[2]** Darrasse L., Ginefri JC.Biochimie 2003 (85):915-37; **[3]** Ratering D. et al. Proc. ISMRM 2007, 383; **[4]** Haueisen R. et al., MAGMA 2006 (19):suppl. 1, 78; **[5]** Radzwill Nl. et al. Proc. ISMRM 2007, 3267

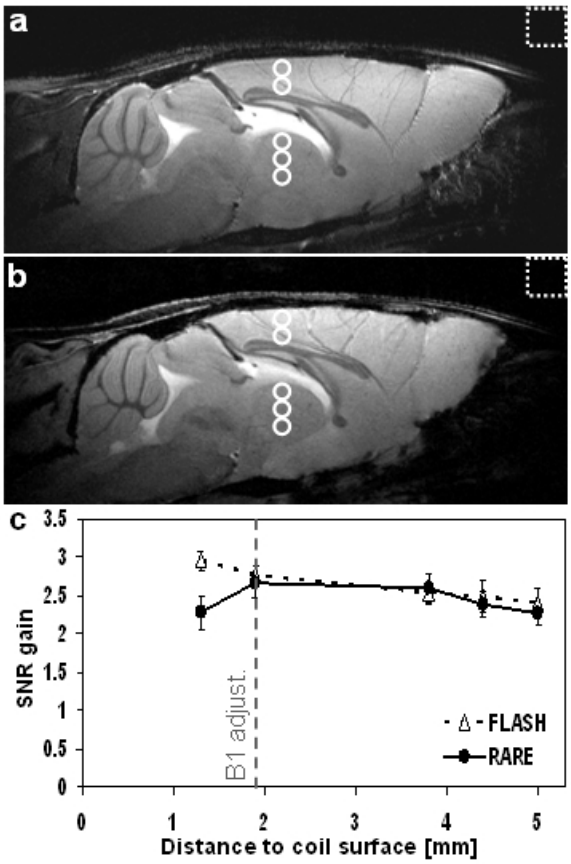

Figure 1: Sagittal images of the mouse brain acquired with the CRP using SE **(a)** and GE **(b)** sequences. SNR calculations were performed for ROIs with increasing distance from the head outer surface (signal: circles; noise: squares). SNR gain of CRP versus RT coil **(c)**. Error bars indicate STDEV(SNR(CRP)) / MEAN(SNR(RT)) for six animals.

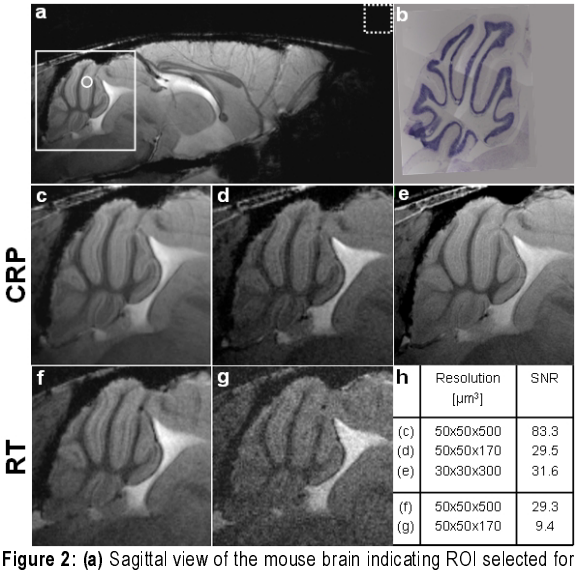

Figure 2: (a) Sagittal view of the mouse brain indicating ROI selected for SNR calculation (signal: circle, noise: dashed square). **(b)** Histological section of the cerebellum (Nissl staining). Cerebellar images acquired using CRP **(c-e)** and RT probe **(f-g)** with respective spatial resolution and resulting SNRs of the different acquisitions **(h)**.