Water or Fat selective 3D-bSSFP imaging combined with banding artifact correction on small-animal at 7T

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TARGET AUDIENCE: This paper is addressed to research teams that need 3D images where water or fat signal can be selectively removed at high magnetic field, for small-animal applications involving detection of metastases within abdomen or quantification of fat content to study diet or drugs effects.

PURPOSE: bSSFP sequence is getting more used in small-animal MR imaging due to the high SNR and (tumor) CNR generated in short acquisition times. However, two major disadvantages exist: the first one is that, similarly to fluids and tumors, subcutaneous and bone marrow fat exhibit hyperintense MR signal. This limits for example (i) the detection of tumors developing within the abdomen, (ii) the volume measurement of metastatic lymph nodes in lymphoma, and (iii) the quantification of fat content during obesity dietary/drug treatments. The second drawback is the banding artefacts inducing signal loss on the bSSFP images. Furthermore, the amount of these artefacts increases when the magnetic field gets stronger. Several techniques have been developed to remove them, including the "Sum-Of-Square" (SOS) technique [1]. However, this technique has never been combined with fat suppression methods. Lots of techniques have been developed to suppress fat signal but with limitations (restriction in TE value, longer acquisition time, sensitivity to magnetic field inhomogeneities). Furthermore, most of them were performed at low magnetic field where banding artifact are few and encountered mostly at the edge of the FOV. Binomial RF pulses allow for frequency selective excitation of protons without increasing acquisition time nor limiting TE values [2]. Thus, the goal of our study was to develop a 3D water-selective or fat-selective bSSFP sequence that generates images free of banding artifact in the entire FOV at high magnetic field (7T).

METHODS: A frequency-selective binomial-shaped water excitation RF pulse (5 sub-pulses; 12321) was inserted into a basic bSSFP sequence (interpulse=200µs ; sub-pulse duration=102.4µs ; total length=1.312ms). No spatial selection was performed.
The water-selective (WS)-bSSFP sequence was performed by centering the binomial pulse to water proton resonance frequency, whereas the fat-selective (FS)-bSSFP sequence was obtained by adjusting the resonance frequency at the fat proton resonance frequency (1050Hz at 7T).
The following parameters were used: flip angle (FA)=25°; reception bandwidth (rBW)=100kHz; repetition time (TR)=minimum. Echo time (TE) was always equal to TR/2. To remove banding artefacts, four resonance frequency offsets were used : 0/42.38/84.76/127.14Hz and -1050/-1092.38/-1134.76/-1177.14Hz, for WS-bSSFP and FS-bSSFP, respectively. The final bSSFP, WS-bSSFP and FS-bSSFP images were reconstructed by applying "Sum-Of-Square" technique with the 4 different offset images.
To image mouse whole-body, FOV=35x22.5x22.5, matrix=256x112x112 and 4 table positions were used. To image the mouse inguinal lymph nodes and vessels, FOV=25x24x22mm and matrix=192x192x192 were used. To image the renal primary tumor (RenCa), FOV=30x22.5x25 and matrix=192x142x160 were used.
Female C57BL/6NCrl mice (N=6, 8 weeks old; Charles River Laboratories, France) were imaged using a horizontal 7T (Bruker, Germany), using an emission/reception birdcage coil (inner diameter: 2.5 cm, 5 cm length). Mice were anesthetized with isoflurane (1%–1.5% in air). The respiration rate was monitored using an air balloon placed on top of the lungs (SA Instruments, Inc., NY, USA).
For the mouse cancer model, female BALB/cByJ (N=6,) were injected with 10^5 mouse renal carcinoma cells (RenCa) in 25µL under the renal subcapsule.

RESULTS/DISCUSSION: Simulations of the application of the binomial pulse within a 3D-bSSFP sequence demonstrated that, when the excitation pulse resonance was centered on the water resonance frequency, 100% of water protons were excited, whereas only 10% of fat protons were generating signal. The banding artifact reconstruction method, inducing a shift of 220Hz in the excitation pulse resonance for short TE, was used. In that case, still 80% of water protons are excited compared to only 5% of fat protons.
A basic bSSFP sequence was performed showing high signal from subcutaneous fat and liquids, like the cephalorachidian liquid in the brain (Figure 1). After applying the water-selective binomial pulse, fat signal was nulled on the entire four FOVs, even in areas that are affected by respiration motion. Furthermore, due to banding artifact reconstruction, the final WS-bSSFP image was also free of banding artefacts. The suppression of fat signal allowed for removing chemical shift artefacts, inducing that lymph node volumes could be more accurately measured and lymphatic vessels more delineated (Figure 2). Finally, a whole-body FS-bSSFP image was performed by increasing the phase offset to -1050Hz. No water signal could be detected even from large blood vessels (Figure 1). This technique allowed to apply a post-processing segmentation and measure accurately fat content.

CONCLUSION: bSSFP sequence can be combined with a frequency-selective binomial pulse to accurately obtain fat or water selective images free of banding artefacts in a mouse whole-body.

REFERENCES: 1. Miraux S et al. 3D TrueFISP Imaging of Mouse Brain at 4.7T and 9.4T. J. Magn. Reson. Imaging 2008;28:497–503; 2. Deligianni X et al. Water-selective Excitation of Short T2 Species with Binomial Pulses. DOI: 10.1002/mrm.24978.

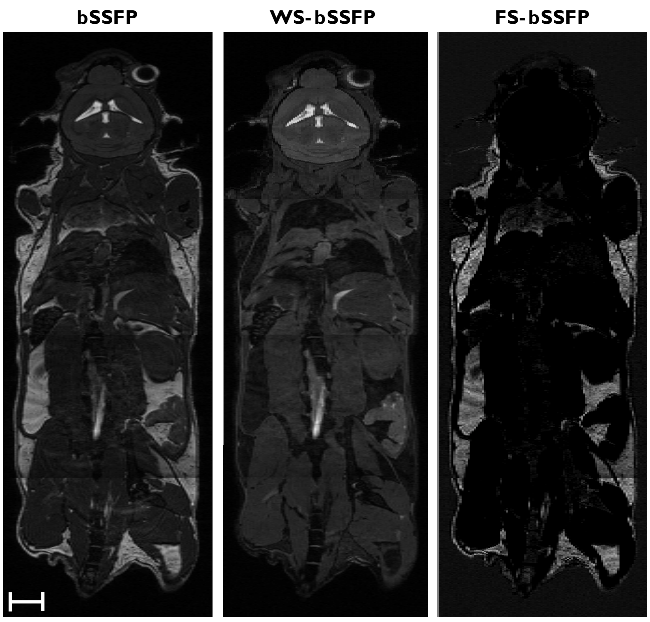

Figure 1 : Mouse whole-body images acquired with basic bSSFP, WS-bSSFP and FS-bSSFP sequences at 7T. Scale represents 5mm.

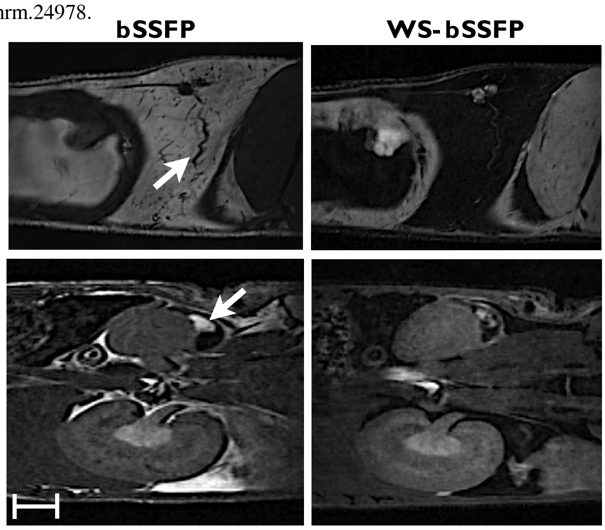

Figure 2 : Saggital images of the mouse inguinal lymph node and its corresponding vessel (arrow) within abdominal fat (top raw). Coronal mouse abdomen images of a RenCa tumor (arrow) developing within the kidney cortex (bottom raw). Images were acquired with basic bSSFP and WS-bSSFP sequences at 7T. Scale represents 1 mm.