Water or Fat selective 3D-bSSFP imaging combined with banding artifact correction for MSK imaging at 3T

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TARGET AUDIENCE: This work is designated to supplement clinical practices for musculo-skeletal MR imaging, in order to increase diagnosis accuracy.

PURPOSE: Musculo-Skeletal (MSK) MR imaging is a common clinical exam. However, the MR sequences used are mainly in 2D, limiting the accuracy of cartilage volume measurement, detection of early-developing oedema or bone metastases, .. 3D-SPGR sequence is performed rarely due to long acquisition time in order to obtain high spatial resolution with sufficient SNR. Furthermore, MR sequences have to efficiently suppress fat signal from the images and thus the corresponding chemical shift artifact, in order to accurately detect synovial fluid and precisely delineate cartilage. There is thus a need to develop a sequence that generates high SNR and high spatial-resolution 3D images in short scan time, while suppressing fat signal.
bSSFP sequence is getting more used in clinical settings due to the high SNR generated in short acquisition times. However, two major disadvantages exist: the first one is the banding artefacts inducing signal loss on the images, that occur every 1/TR (Repetition Time). Furthermore, the amounts of these artefacts increase when the magnetic field gets stronger. Several techniques have been developed to get rid of them, including the "Sum-Of-Square" (SOS) technique. The second drawback is that fluid, cartilage fatty bone-marrow and sub-cutaneous fat exhibit similar hyperintense MR signal, limiting the accuracy of detection of synovial fluid at the knee joint, ligaments or bone-marrow oedema. Lots of techniques have been developed to suppress fat signal but with limitations [1-5]. Furthermore, most of them were performed at low magnetic field and very few were combined with a banding artifact reconstruction.
Thus, the goal of your study was to develop a 3D-bSSFP sequence that generates images free of banding artifact and where fat signal is suppressed in the entire FOV at high clinical magnetic field (3T).

METHODS: A 3T scanner (Achieva, Philips, Best, The Netherlands) was used to acquire knee, abdomen and ankle images of three male volunteers (age range, 28–38 years; mean age, 33.6 years) using a 8-channel knee coil, a 16-channel abdomen coil and 2 flex surface coils, respectively. The study was approved by our institutional review board for human subjects. Before imaging, informed consent was obtained from all volunteers.
A frequency-selective binomial-shaped water excitation RF pulse (4 sub-pulses; 1331) was inserted into a basic bSSFP sequence (interpulse=730µs ; sub-pulse duration=200µs; total length=2.9ms). No spatial selection was performed.
Increasing values of TE were tested: 3.9 and 7.5ms. Echo time (TE) was always equal to TR/2. To remove banding artefacts, 4 images were acquired at 4 different resonance frequencies (On Resonance (OR); OR+1/TR; OR+2/TR; OR+3/TR). The final bSSFP images were reconstructed by applying SOS technique with 4 (SOS4) or 2 (SOS2) different resonance frequency offset images.
For knee imaging, the WS-bSSFP sequence was performed with the following parameters: FOV=160x160x140mm; matrix=288x288x140; flip angle=27°; reception bandwidth=754.8Hz; acquisition time=3min43s. Furthermore, parallel imaging using SENSE factors of 2, 3 and 4 was applied to reduce the acquisition time of the 3D WS-bSSFP sequence. To image ankles, only the following parameters were modified: FOV=160x160x100; matrix=288x288x100.

RESULTS/DISCUSSION: Simulations demonstrated that increasing TE/TR would induce numerous banding artefacts, getting the SOS reconstruction more challenging. Furthermore, the lower the flip angle the more intense the banding artefacts. However, as flip angle increased, tissue SNR decreased. Thus, the best compromise was 30°. Shifting the resonance frequency of images in order to remove banding artefacts on the bSSFP images, still induced that 90% of water protons got excited compared to only 10% of fat protons.
Images acquired with basic 3D-bSSFP sequence at 3T (Figure 1) prevented the detection of synovial fluid as the hypersignal engendered from this fluid was similar to the one from fat. However, as soon as the binomial pulse was applied, the signals from both subcutaneous fat and from bone marrow were nulled highlighting the precise location of the fluid at the joint and of the cartilage. The fat signal was suppressed on the entire knee image. Banding artefacts were efficiently removed from the final images by applying SOS4, even when TE was set to 7.5ms. After SOS2 reconstruction, the WS-bSSFP images still exhibited a homogeneous fat-nulled signal in the entire FOV. However, some banding artefacts were still visible on SOS2 but they were located only at the edges of the FOV. By applying parallel imaging (SENSE), a 3D WS-bSSFP image of the knee was obtained in less than 2min, with good quality. This result could be even more improved by using 16-channel coils.
Like for the knee, 3D WS-bSSFP sequence was efficient to remove bone marrow and subcutaneous fat signals at the ankle level (Figure 2), where field inhomogeneity is higher than on the knee. This highlights the robustness of our method for clinical practice.

CONCLUSION: 3D bSSFP sequence can be combined with a binomial pulse to accurately suppress fat signal and also banding artefacts in an entire FOV. Compared to other fat-suppression techniques, no restriction in the TE/TR values was needed. In order to decrease acquisition time, only 2 phase offsets can be acquired combined with parallel imaging, still providing a high quality image with very few banding artefacts.

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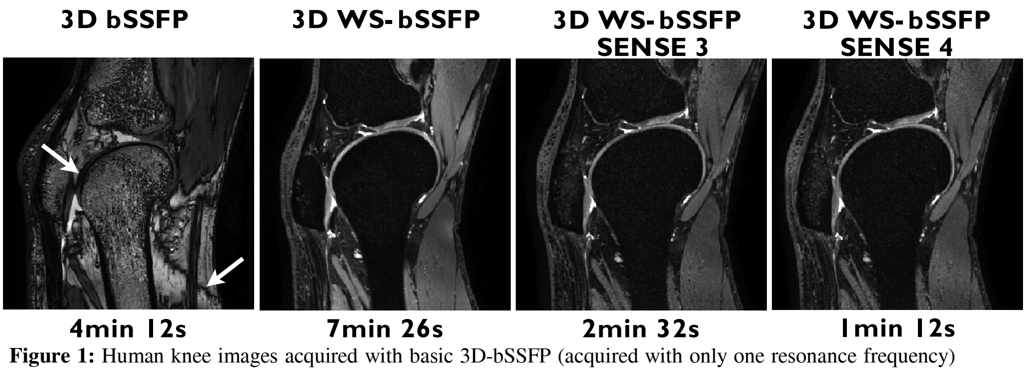

Figure 1: Human knee images acquired with basic 3D-bSSFP (acquired with only one resonance frequency) and 3D WS-bSSFP (SOS2) acquired without or with parallel imaging (SENSE 3 and SENSE 4). The resolution was around 500µm isotropic. The arrows show banding artefacts in the cartilage and in the sub-cutaneous fat.

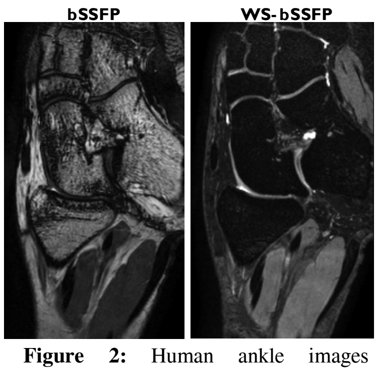

Figure 2: Human ankle images acquired with basic 3D-bSSFP and 3D WS-bSSFP with a resolution of around 500µm.