

# Spin-Echo Micro-MRI of Trabecular Bone Using an Improved 3D FLASE Sequence

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## Introduction

The recognition of the role of trabecular bone (TB) architecture as an independent predictor of bone strength has spurred the development of noninvasive imaging methods. Recent advances in imaging technology now permit in vivo imaging of TB at a resolution adequate for analysis of the 3D architecture of the TB network [1]. Spin-echo imaging has proven to be advantageous since it is less sensitive to the deleterious effects from local gradients at the bone-bone marrow interface [2]. 3D FLASE [3, 4] is a high flip-angle pulse sequence enabling scanning at a high resolution in a clinically practical scan time. The version of the method used previously had limitations, including stimulated echo artifacts from imperfections in the nonselective phase-reversal pulse and poor motion tracking of the gradient-echo navigators. Here we report a significantly improved pulse sequence that resolves these shortcomings.

## Theory and Methods

The FLASE pulse sequences (original and modified) are shown in Figure 2; the modified sequence incorporates a number of improvements in areas of artifact suppression and motion correction. Because the 180 degree refocusing pulse is non-selective, there is a potential for magnetization to be excited outside of the field of view. Indeed, even modest B1 field inhomogeneity can cause undesired transverse magnetization to be excited over a large volume, often causing spurious echoes during imaging. Within a single repetition, this problem can be handled very well using crusher gradients and phase cycling (to push any artifacts to the edge of the field of view). A more serious problem occurs when magnetization is refocused and appears in a subsequent repetition as a stimulated echo, causing a banding (streaking lines) artifact (see Figure 1 and [5]). This complex phenomenon is difficult to predict or correct, as the effect varies from one subject to the next. To overcome these problems, two modifications were made to the pulse sequence. First, the prephasing of the readout gradient is placed after (rather than before) the refocusing pulse (at the expense of a small increase in TE). This ensures that any stimulated echo will at least not be offset from the main echo in the  $k_x$  direction (eliminating the possibility of banding). Second, a random offset to the transmit/receive phase is applied at the beginning of each repetition, causing any systematic stimulated echoes to be phase-incoherent, and preventing localized artifacts from appearing in image space.

The new FLASE protocol also includes improved navigator motion detection. Rather than using magnetization left over from the imaging signal [4], the new protocol includes a separate excitation pulse for the navigator acquisition. In order to avoid a loss in SNR efficiency, a slice adjacent to the imaging slab is excited. In this manner, the navigator signal-to-noise ratio is enhanced thereby improving overall sensitivity in motion detection (see [6]).

Finally, in order to reduce aliasing artifacts caused by a too-small FOV in the phase-encode direction (Figure 1), the corners of kYZ space are not acquired in the modified protocol, i.e. a cylindrical k-space volume is acquired. The time saved is used to increase the FOV in the in-plane phase-encoding direction, preventing FOV wrapping into the region of interest.

## Results

The improved FLASE pulse sequence was used in a clinical research study currently in progress involving over fifty scans of the distal tibia. Motion correction seemed to be adequate for most of the scans, and no non-motion related MRI artifacts were observed in any of the images. Figure 3 shows one image acquired with the new protocol. Also, a high-quality 3D skeleton is displayed enabling visualization of the intricate TB architecture.

## Conclusion

A modified 3D FLASE pulse sequence has been described for micro-MRI of trabecular bone. The new sequence involves a number of improvements in motion correction as well as MRI artifact reduction.

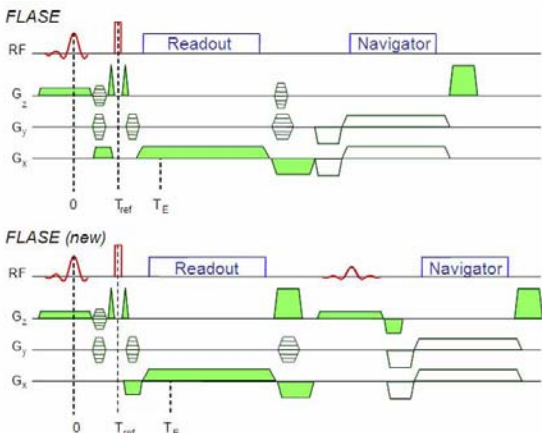


Figure 2. Diagram for the original and modified FLASE pulse sequences. The new sequence involves a number of improvements, including a separate navigator excitation pulse, and modifications to reduce stimulated echo artifacts.

## References

- [1] Wehrli et al, Proc IEEE 91: 1520-1542, (2003); [2] et al, J Magn Reson Imaging 22: 647-55 (2005);  
[3] Ma et al, Magn Reson Med 35:903-910 (1996); [4] Song et al, Magn Reson Med 41:947-953 (1999);  
[5] Vasilic et al, Magn Reson Med 52:346-353 (2004); [6] Magland et al, ISMRM Proceedings 2006;

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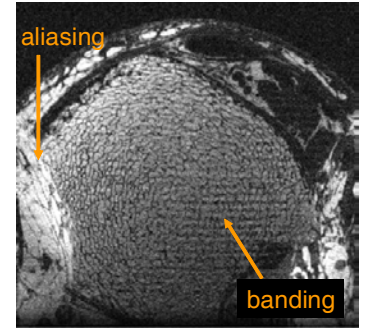


Figure 1. Potential problems with the original FLASE protocol include field of view wrapping (aliasing) and stimulated echo (banding) artifacts.

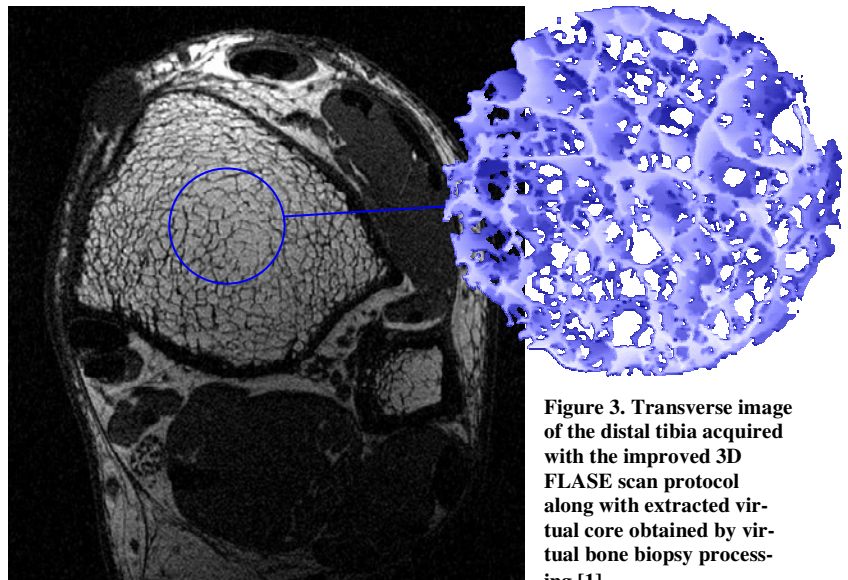


Figure 3. Transverse image of the distal tibia acquired with the improved 3D FLASE scan protocol along with extracted virtual core obtained by virtual bone biopsy processing [1].