

# Fast Low-Angle Dual Spin-Echo (FLADE): A New Pulse Sequence for Micro-Imaging of Trabecular Bone

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## Introduction

The architecture of trabecular bone plays a pivotal role in conferring strength to the skeleton. Recent advances in MR imaging technology have made possible direct imaging of the 3D architecture of trabecular bone at selected skeletal locations [1,2]. Spin echo approaches have proven useful, as they are less sensitive to artifacts from local susceptibility induced gradients in the vicinity of trabeculae [3]. The FLASE pulse sequence, originally conceived by Ma et al. [1] has been successful but has some flaws. Here we introduce a new pulse sequence, Fast Low-Ange Dual Spin-Echo (FLADE), that is more robust and that offers enhanced capabilities for motion correction during the scan.

## Methods

The FLADE and FLASE pulse sequences are depicted in **Figure 1**, and the key parameters are shown in **Table 1**. Note that in this protocol the resolutions are identical and the scan times are approximately the same. The main difference between the sequences is that FLADE involves two spin echoes per repetition (rather than one). A consequence of having two refocusing pulses is that the optimal flip-angle is less than 90 degrees. Thus FLADE avoids the difficulties associated with the large flip-angle excitation of FLASE [1,4]. The additional spin echo also allows FLADE to use a significantly higher receiver bandwidth while keeping the same overall acquisition time per repetition. The first echo acquires 75% of k-space in the readout direction, while the second acquisition is a full readout. Phase encoding gradients are applied in two directions (Y and Z), but only half of kZ-space is sampled (the missing half is filled by complex conjugation). As a result, FLADE involves only half the number of phase encoding steps of FLASE, enabling a significantly increased repetition time (150 ms as compared to 80 ms for FLASE). In order to attain the desired echo time, FLASE only acquires 60% of kX-space, requiring that kY- and kZ-space must be sampled fully for FLASE.

The longer repetition time of FLADE is used for measuring patient motion with increased precision. As shown in **Figure 1**, two navigator excitations are applied during each acquisition. To avoid a decrease in the imaging signal, the two navigator pulses excite slices above and below the imaging slab. Projections are obtained in the two in-plane directions, and the two navigator readouts provide independent measurements of the 2D translational patient motion.

FLASE and FLADE were implemented on a 1.5T clinical scanner (Siemens Sonata) using a custom-made elliptical birdcage coil. In-vivo images of the wrist were acquired for each sequence on a number of volunteers. A 3D dataset was reconstructed for each of the two FLADE echoes, and these were combined into a single image using a simple linear combination after phase correction.

## Results and Discussion

Figure 2 shows in-vivo FLASE and FLADE images. The quality of the FLADE images was found to be comparable to that of the FLASE images. The increased repetition time of FLADE provides two main advantages, which were evident in our experiments but not illustrated due to space limitations. First, a reduction in artifacts caused by inter-repetition stimulated echoes [4]. Second, an increase in the accuracy of the navigators used to measure patient motion.

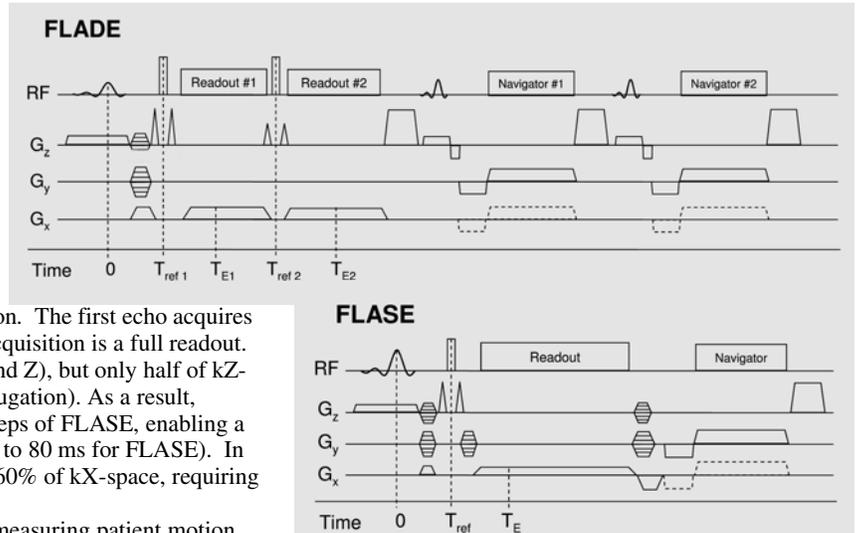
## Conclusion

FLADE is a new pulse sequence for high resolution imaging of trabecular bone. Like FLASE, the sequence produces high-quality spin-echo images in a clinically tolerable scan time. In addition, FLADE has certain advantages making it more robust and providing improved motion correction.

## References:

- [1] Ma et al. Magn Reson Med 35:903-910 (1996).
- [2] Majumdar et al. Top Magn Reson Imaging 13:323-334 (2002).
- [3] Techawiboonwong et al. J Magn Reson Imaging, in press (2005).
- [4] Vasilic et al. Magn Reson Med 52: 346-353 (2004).

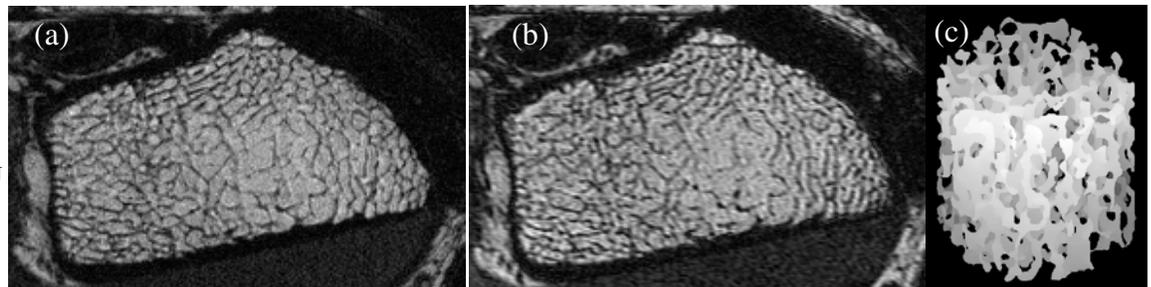
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**Figure 1:** Pulse sequence diagrams for FLADE and FLASE.

	FLASE	FLADE
Field of View	39x70x13 mm <sup>3</sup>	39x70x13 mm <sup>3</sup>
Resolution	137x137x410 μm <sup>3</sup>	137x137x410 μm <sup>3</sup>
Scan Time	12.5 Minutes	11.5 Minutes
Receiver Bandwidth	32 Hz/pix	64 Hz/pix
TR / TE	80 ms / 10 ms	150 ms / 11 and 29 ms
Flip Angle	140 degrees	60 degrees

**Table 1:** Sequence Parameters for FLASE and FLADE



**Figure 2:** In-vivo images of the distal radius showing similar image quality between (a) FLASE and (b) FLADE. (a) and (b) are single slices of 3D datasets; (c) is a 3D core derived from the FLADE dataset shown in (b).