3D Wideband Late Gadolinium Enhancement (LGE) MRI for Patients with Implanted Cardiac Devices

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Purpose. Late gadolinium enhancement (LGE) cardiac MRI is the clinical gold standard for non-invasive characterization of myocardial scar, and plays an important role in identification of non-ischemic cardiomyopathy [1]. However, a large number of patients who may benefit from LGE MRI have preexisting implanted cardiac devices such as implantable cardioverter defibrillators (ICD), which can produce hyper-intensity artifacts over a large portion of the heart obscuring scar regions. Recent studies have shown that these hyper-intensity artifacts can be mitigated by using a wideband inversion recovery (IR) pulse in the LGE sequence [2-3]. These studies used a 2D IR-FLASH sequence with 8 mm thick slices for LGE. While this sequence is sufficient for identification of scar, a 3D sequence with thinner slices would provide more detailed information about scar transmurality and enable identification of focal lesions [4]. The current study describes our initial experience of developing and optimizing a 3D wideband LGE MRI sequence in patients with ICDs.

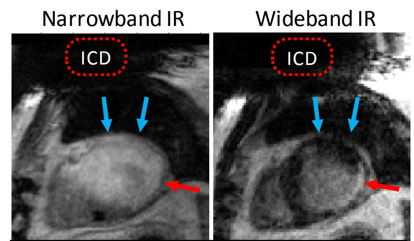

Fig. 1: 3D LGE (Sequence A) in an ICD patient. The left image shows hyper-intensity artifacts (blue arrows) that occur when using the conventional narrowband IR pulse The right image shows that hyper-intensity artifacts are eliminated using the wideband IR pulse. Scar tissue (red arrow) is apparent only in the absence of hyper-intensity artifacts.

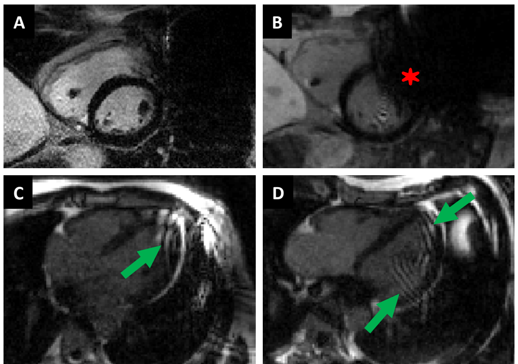

Fig. 2. A: 2D LGE in an ICD patient; **B:** signal void in 3D LGE (Sequence A) in the same ICD patient as (A) (same slice location); **C & D:** banding artifacts in 3D LGE (sequence A) from two normal volunteers (non-contrast).

Methods. **Part 1.** We initially implemented the wideband IR pulse (spectral bandwidth: 3.8 kHz) in a 3D IR-FLASH sequence with cross-beam respiratory-gating navigator pulses (Sequence A). Initial testing on phantom and normal volunteers indicated that Sequence A worked well. Sequence A was used to image 5 normal volunteers (in whom an ICD was attached near the left shoulder) and 4 ICD patients. These images revealed that signal void and banding artifacts appear in Sequence A, which do not appear in the corresponding 2D wideband LGE images. Further testing with phantoms suggested these signal void and banding artifacts are due to slab distortion caused by off-resonance produced by the ICD. **Part 2.** Slice selection is governed by the expression $\omega_{RF}/(\gamma G_{SS})$, where G_{SS} is the slice selection gradient. In the presence of off-resonance, the slice profile is distorted, and the amount of distortion is given by $\omega_{off}/(\gamma G_{SS})$, where ω_{off} is the off-resonance frequency (frequency offset). Therefore, when imaging a 100 mm slab with Sequence A, at a distance of 7 cm from an ICD (ω_{off} = 3 kHz) [2] the slab distortion would be 50 mm (bandwidth for RF excitation pulse = 6 kHz in Sequence A). Such a large distortion can give rise to an increased signal void compared to a 2D sequence. In addition, the distorted signal can wrap-around along the slice encode direction and overlap with the image slab. Banding artifacts can be produced in the region of overlap, since the spatial phase variation in the two overlapping regions would be different. Phantom scans were carried out to verify these effects. **Part 3.** The slab distortion expression suggests that slab distortion can be reduced by using a higher G_{SS}. A higher G_{SS} can be used for the same imaging volume if the bandwidth of the RF excitation pulse is increased (since slab thickness = $BW_{RFex}/(\gamma G_{SS})$). So, we modified Sequence A by increasing the bandwidth of the RF excitation pulse from 6 kHz to 12 kHz (Sequence B). We compared Sequence B with Sequence A in phantom experiments, and tested Sequence B in 2 ICD patients.

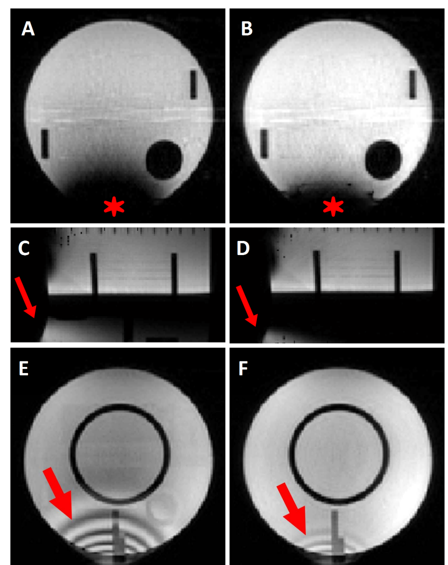

Fig. 3. Left column are Sequence A images, and right column are sequence B images. **A&B:** Signal void (red*) in Sequence A, which is reduced in Sequence B. **C&D:** Slice wrap-over in Sequence A (red arrow), which is reduced in Sequence B. **E&F:** Banding artifacts from slice overlap in Sequence A, which is reduced in Sequence B.

Results. **Part 1.** The wideband IR pulse was successfully implemented in Sequence A, and worked well to remove hyper-intensity artifacts (Fig. 1). Signal voids and banding artifacts were formed in the LGE images of the remaining 3 patients and all normal volunteers. Examples of artifacts are shown in Fig. 2. **Part 2.** Fig. 3 shows phantom images demonstrating the formation of signal void (Fig. 3A), slice wrap-over (Fig. 3B) and banding artifacts Fig. 3C) in Sequence A. The banding artifacts can also be reduced in Sequence A by increasing slice oversampling, although this does not improve the signal voids and results in increased scan time. **Part 3.** Phantom experiments showed that Sequence B was successful in reducing signal void (Fig. 3B), slice wrap-over (Fig. 3D) and banding artifacts (Fig. 3F) compared to Sequence A. In the 2 patients scanned with Sequence B, no artifacts were produced in one patient, while slight banding artifacts were produced in the second (Fig. 4). No signal void was produced in either patient.

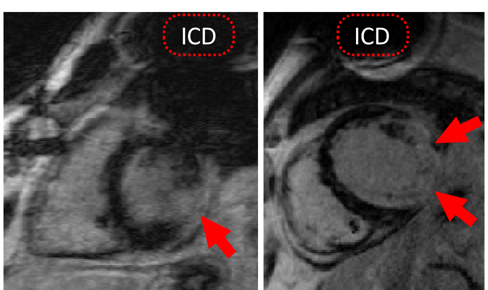

Fig. 4. 3D wideband LGE images (Sequence B) from two ICD patients, showing significantly reduced artifacts. Red arrows indicate scar tissue.

Discussion. Our 3D wideband LGE sequence has 2 x 2 x 4 mm spatial resolution, which is higher than the typical 2D LGE sequence, especially in the slice encoding direction. This is crucial for detailed myocardial scar characterization. It is also important for obtaining a better understanding of scar mediated ventricular arrhythmias and for guiding radiofrequency ablation procedures for ventricular tachycardia.

Conclusion. We have developed a modified 3D wideband LGE sequence which reduces hyper-intensity artifacts that occur in conventional 3D LGE and tested it in ICD patients. The pulse sequence parameters were optimized to reduce signal void and distortion artifacts caused by an ICD. Our latest results on patients using this wideband 3D LGE sequence yielded minimal additional artifacts compared to traditional 2D LGE and higher spatial resolution. This represents a first step towards application of 3D LGE imaging in ICD patients in a clinical setting.

References. [1] Simonetti OP, et al. Radiology 2001, 218(1), 215; [2] Rashid S, et al. Radiology. 2013, *E-pub Ahead of Print;* [3] Stevens SM, et al., Heart Rhythm, 2013 Oct., *E-pub Ahead of Print*; [4] Kino A, et al., Int J Cardiovasc Imaging 2011, 27, 527.