Improved Late Gadolinium Enhancement Cardiac MRI for Patients with Implanted Cardiac Devices

Shams Rashid[1], Stanislas Rapacchi[1], Kyung H. Sung[1], Marmar Vaseghi[2], Kalyanam Shivkumar[2], J. Paul Finn[1], and Peng Hu[1]

[1]*Radiological Sciences, University of California Los Angeles, Los Angeles, CA, United States,* [2]*Cardiac Arrhythmia Center, University of California Los Angeles, Los Angeles, CA, United States*

Introduction. Late gadolinium enhancement (LGE) MRI is the clinical gold standard for non-invasive myocardial tissue characterization. Recent literature shows that cardiac MRI (CMR), including LGE CMR, can be safely performed in patients with implanted cardiac devices, such as ICDs and pacemakers (1-2). However, the current LGE sequence suffers from hyperintensity artifacts as shown in Fig. 1. These image artifacts prevent assessment of myocardial scar on millions of patients with these devices who will highly likely need a CMR exam within their lifetime. Although these image artifacts have been documented (1-2), no solutions have been proposed for this problem. We hypothesize that the hyperintensity artifact arises because of off-resonance induced by the cardiac device, which prevents spins in the affected myocardiumfrom from being inverted by the non-selective inversion pulse typically played in a LGE pulse sequence due to the limited spectral bandwidth (BW) of the inversion pulse. We propose that this artifact can be resolved by using an inversion pulse with higher BW, and in which the center of the modulation frequency is shifted to encompass the off-resonant spins.

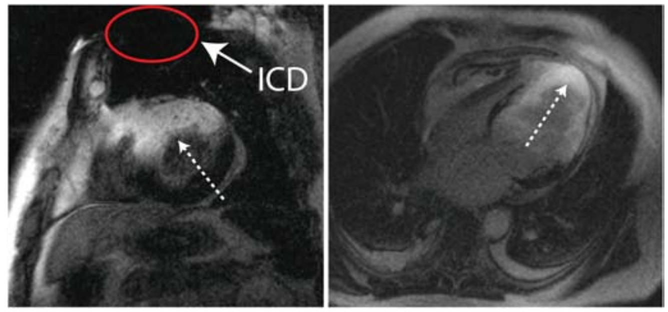

Fig. 1: Typical LGE images (using the narrowband inversion pulse normally used in clinic) from two patients with ICDs. The metal casing of the ICD produces hyperintensity artifacts (dashed arrows) which prevent assessment of myocardial scar in the affected regions.

Methods. The hyperbolic secant (HS) pulse, the most widely used adiabatic inversion pulse (3), has an amplitude modulation given by $A(t) = A_0 \operatorname{sech} \beta t$, and a phase modulation given by $\phi(t) = \mu \ln(\operatorname{sech} \beta t) + \mu \ln A_0$, where A_0 is the peak B_1 field, β is a frequency modulation parameter and μ is a dimensionless parameter. The spectral BW is given by the product $\mu\beta$. To fulfill the adiabatic condition, the peak amplitude A_0 must be greater than $\sqrt{\mu}\beta/\gamma$. The center of the modulation frequency can be shifted by adding the term ωt to the phase modulation function, (ω: frequency shift value). We designed a HS inversion pulse using β = 750 rad/s and μ = 10, which yielded a BW of 2.4 kHz. This wideband inversion pulse was subsequently implemented in the LGE sequence, replacing the original HS inversion pulse with 1 kHz BW. The new sequence, along with the standard LGE sequence, was used to conduct LGE CMR in a healthy volunteer, with an ICD placed below the shoulder blade. The volunteer received an IV injection of Gd 15 minutes prior to imaging. The standard LGE was repeated after removal of the ICD. The sequences were also tested on two patients with ICDs (post Gd injection) who were scheduled to undergo catheter ablation of ventricular tachycardia.

Results & Discussion. LGE images from the healthy volunteer (post Gd injection) are shown in Fig. 2. The standard LGE sequence, which uses the narrowband inversion pulse, was used without the ICD attached (Fig. 2A), and repeated with the ICD taped below the shoulder (Fig. 2B). The apical region of the heart suffers from the off-resonance hyperintensity artifacts when the ICD is present, as indicated in Fig. 2B (arrow). This artifact is completely resolved using our new LGE sequence with a wideband inversion pulse (Fig. 2C). LGE images from the ICD patients are shown in Fig. 3. The standard LGE sequence produces hyperintensity artifacts at the septum and apex of patient 1 (Fig. 3A, arrows), which are resolved using our LGE sequence (Fig. 3B). Although no scar tissue was detected in this patient, if any scar was present, it would not have been detectable using the standard LGE sequence. In patient 2, the artifact produced by the standard sequence (Fig. 3C, yellow arrow) may appear as a scar, but it was resolved by the new sequence (Fig. 3D). Patient 2 had ventricular wall thinning and possible scar tissue near the apex of the left ventricle (Fig. 3 C & D, red arrow).

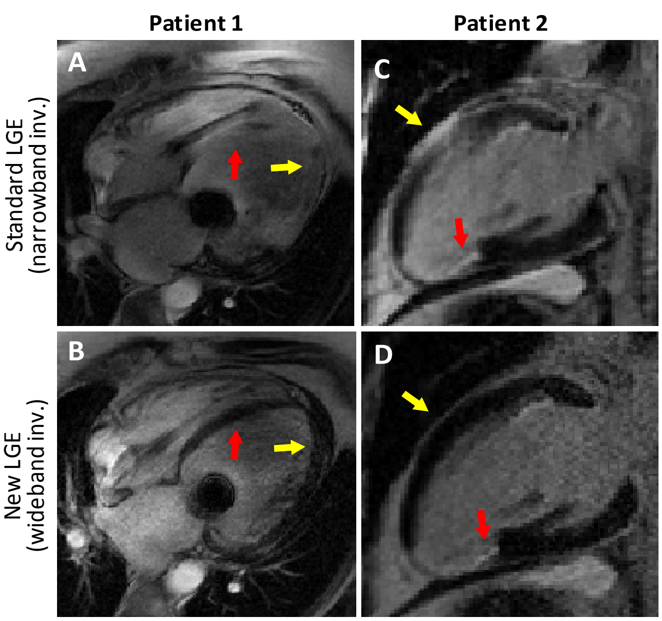

Fig. 3: LGE images from two patients with ICDs (post Gd injection) acquired using the standard LGE sequence (A & C) and repeated with the proposed sequence (B & D), which uses the wideband inversion pulse. In patient 1 (A & B), myocardium at the septum (red arrows) and left ventricular wall (yellow arrows) appear hyperintense when the narrowband inversion pulse is used, whereas they have the characteristic suppressed signal when the wideband inversion pulse is used (B). No myocardial scar was detected in patient 1. In patient 2, the standard LGE sequence gives rise to a hyperintensity artifact (yellow arrow) which may appear as a scar (C), but is resolved using the new LGE sequence (D). Patient 2 had ventricular wall thinning and possible scar tissue near the apex (C & D, red arrow).

Conclusion. We developed a technique to prominently reduce the hyper-intensity artifacts seen in LGE CMR of patients with cardiac devices. We expect our technique to be widely applicable and to lead to increased application of MR scar imaging for the large population of patients with cardiac devices who need a cardiac MRI.

References:

1. Sasaki T, et al., *Circ. Cardiovasc. Imaging,* 2011; 4:662

2. Nazarian S, et al., *Circulation,* 2006; 114:1277

3. Bernstein MA, et al., *Handbook of MRI Pulse Sequences,* 2004; Elsevier Acad. Press, Burlington, MA.

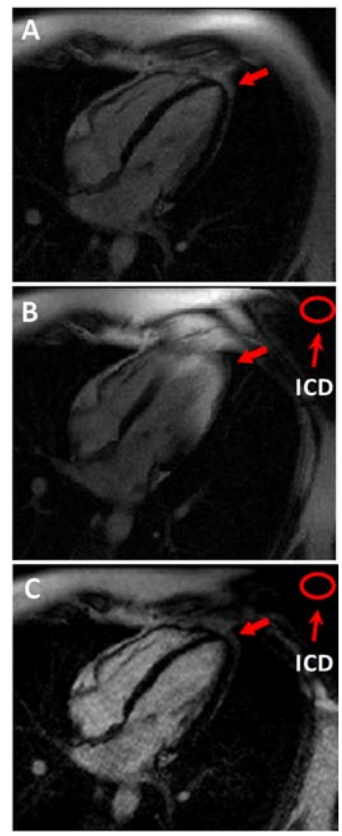

Fig. 2: LGE images from a healthy volunteer (post Gd injection). The standard LGE sequence was used without the ICD attached (A) and with the ICD attached below the shoulder (B). The hyperintensity artifact, caused by off-resonance induced by the ICD, is indicated by the red arrow in (B), compared to myocardial signal suppression in (A) (red arrow). The artifact is completely eliminated using our wideband inversion pulse with the ICD in place (C, red arrow).