Myocardial skeletal muscle signal spoiling using a crusher coil: a human cardiac phosphorus (31P) MR spectroscopic imaging study at 7 Tesla

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Background
31P-MRS provides direct insights into myocardial energy supply (ATP, ADP, phosphocreatine (PCr) and inorganic phosphate). An initial study demonstrated that 7T cardiac 31P-MRS has 2.8x greater SNR than at 3T. However, the translation of more sophisticated 31P-MRS protocols to 7T is particularly challenged by increased RF heating of tissue at 7T. Chen and Ackerman introduced the surface spoiling coil in 1990: a concept that was recently further developed (Boer MRM 2014) for lipid suppression in human brain 1H-CSI. In this work, we introduce the first crusher coil for cardiac 31P-MRS at 7T. This allows us to saturate more efficiently skeletal muscle signal removing the RF heating associated with RF saturation bands.

Methods
Data were acquired with a Siemens 7T scanner. Localization used a 10cm 1H Tx/Rx RF coil (Rapid Biomedical) to acquire CINE FLASH images. 31P-MR spectra were acquired with a custom 10cm 31P Tx/Rx loop. The magnetic field generated by the crusher coil was simulated and optimized using Matlab (Mathworks). A capacitor initially charged by a power supply unit (PSU) was used to drive the current pulse in the crusher coil during a short spoiling duration (100μs). Spoiling was timed to coincide with the existing phase encoding gradients. A 2D-CSI experiment was performed on a two-compartment phantom with the 31P RF coil and the crusher coil placed above it. The BISTRO saturation band (Luo, MRM 2001) covered the entire top slice. The spoiling efficiency was then confirmed in vivo using 3D-CSI.

Results
The coil geometry was optimized to saturate skeletal muscle (<40mm) with minimal disruption of cardiac signals (>70mm) (Fig. 1A-B). Currents up to 35A were produced through the crusher coil (Fig. 1C). In the 2D CSI in vitro experiment (Fig. 1D), the bottom slice signal remained stable, while the top slice signal was spoiled differently depending on the acquisition protocol. The SAR-limited BISTRO saturation bands reduced the mean signal in the entire top slice to 52% of the original signal. A similar signal reduction (45%) occurred when using the crusher coil at 13A. When combining the BISTRO saturation bands and the crusher coil (13A), the mean signal was reduced to 15%. The current in the crusher coil was increased up to 17A, yielding to a 35% signal reduction. In 3D-CSI in vivo study, mean skeletal muscle signal was reduced to 52% with BISTRO and to 40% with the crusher coil (Fig. 2). The PCr/ATP ratio in the septum was 2.3 (BISTRO) and 2.1 (crusher). SAR was 97% (BISTRO) and 16% (crusher).

Conclusions
A crusher coil is an efficient alternative to BISTRO saturation bands for suppressing skeletal muscle during cardiac 31P-MRS at 7T. The flexibility offered by using the crusher coil will allow us to employ sequence modules that would otherwise be SAR-prohibitive e.g. adiabatic excitation for absolute quantitation, 31P NOE enhancement or saturation-transfer pulses for future clinical studies at 7T, without having to compromise the skeletal muscle suppression.
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