Heteronuclear Single Quantum Coherence (HSQC) MRS in Humans at 7 T

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Introduction – Carbon-13 (^{13}C) MRS has an intrinsically low NMR sensitivity that often leads to large acquisition volumes or long scan times. While the use of higher magnetic fields can overcome the sensitivity limitations, high radiofrequency (RF) power deposition associated with proton-decoupling limits the achievable gain. Two-dimensional (2D) heteronuclear single quantum coherence (HSQC) MRS is a method that uses the high chemical specificity of ^{13}C MRS while retaining the high sensitivity of ^{1}H detection. Due to the 2D nature of the method, proton-decoupled ^{13}C MR spectra can be obtained without the use of high-powered decoupling pulses.

Methods – All experiments were performed on a 7 T MR system (Agilent, Santa Clara, CA, USA) using a home-built, single ^{1}H surface coil (Ø 80 mm) and a pair of ^{13}C surface coils (Ø 130 mm) driven in quadrature. The HSQC method is built on STEAM localization whereby the TM period becomes the indirect t_1 sampling period, broken up by a ^{1}H inversion pulse to refocus heteronuclear J coupling. ^{13}C excitation pulses surrounding the t_1 delay transfer coherences between the ^{1}H and ^{13}C channels, whereby magnetic field gradients (2:2:1 area ratio) eliminate all signals without ^{1}H-^{13}C scalar coupling. The low RF power deposition allowed t_1-dependent TR variation (TR_{max}/TR_{min} = 3000/500 ms) to accelerate data acquisition 2.6-fold. Controlled aliasing over an indirect spectral width of 2.0 kHz gave an additional 4.5-fold acceleration for a final acquisition time of 2.4 min per average (128 t_1 increments). *In vivo* HSQC spectra were acquired in 19 min from a 9.0 mL volume positioned in the adipose tissue surrounding the leg muscle (n = 6, Fig 1B).

Results – Fig. 1C shows a typical 2D HSQC spectrum acquired from human adipose lipids *in vivo* at 7 T. The high-sensitivity and spectral resolution allows the identification of 19 unique resonances corresponding to the various lipid chain carbons (Fig. 1A). The small indirect spectral width of 2.0 kHz led to aliasing of resonances (indicated by *). However, controlled aliasing by judicious choice of spectral width and offset avoided spectral overlap. TR variation led to small line broadening along the ^{13}C dimension, in good agreement with theoretical predictions. *In vivo* HSQC spectra of all 6 subjects were of high-quality (i.e. no detectable t_1 noise, high spectral resolution) and similar to *in vitro* HSQC spectra on vegetable oils.

Discussion – It has been demonstrated that high-quality 2D HSQC NMR spectra can be acquired from human adipose tissue at 7 T. The HSQC method is methodologically simple and robust and is flexible regarding trade-offs between temporal and spectral resolution. 2D HSQC has a strong potential to become a default method in natural-abundance or ^{13}C-enriched studies of human metabolism *in vivo*.

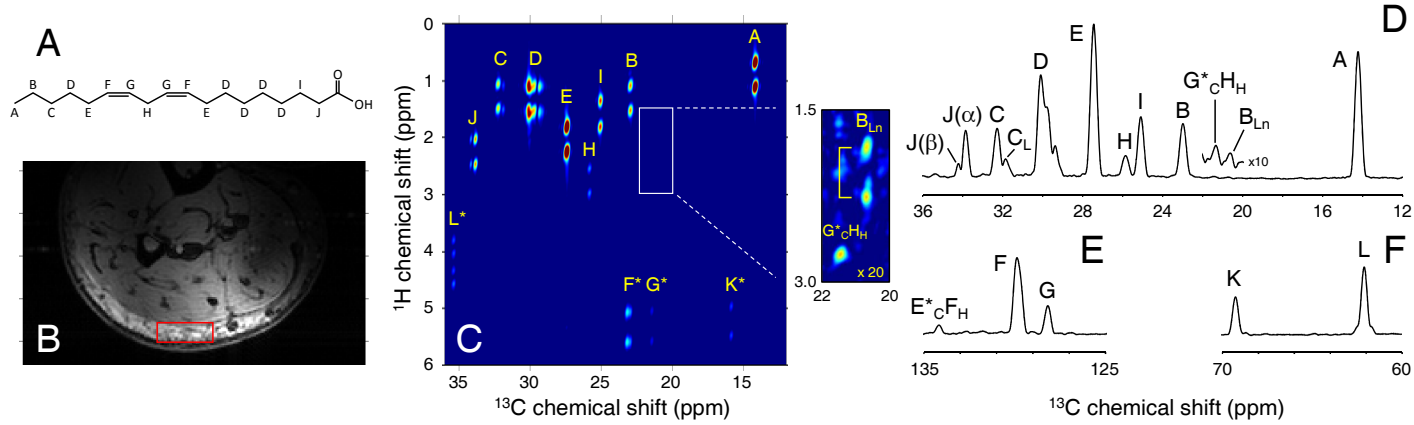

Figure 1: (A) Structure of linoleic acid which would be esterified to glycerol (carbons K and L) in a triglyceride. (B) Anatomical MRI of the leg showing the placement of a 3 x 1 x 3 cm voxel. (C) 2D HSQC spectrum acquired from human leg *in vivo* in 19 min with TR variation (TR1/TR2/T_1 = 3000/500/1000 ms). Labels with an asterisk (*) indicate that the resonance is aliased along the ^{13}C dimension by an integer number of the ^{13}C spectral width (= 2 kHz). The inset shows the linolenic acid resonance B_{Ln} with a 20-fold increased vertical scale, together with a ^{1}H-^{13}C resonance from correlation over multiple chemical bonds (HMBC) between the G position ^{13}C nucleus and the H position protons. (D) 1D projection of the ^{13}C fingerprint region summed over proton chemical shifts between 0.0 and 3.5 ppm. (E/F) 1D projection of the double-bond carbons (E) and glycerol carbons (F) summed over proton chemical shift ranges [4.5 . . . 6.0] ppm and [3.5 . . . 6.0] ppm (after appropriate ^{13}C frequency shifting), respectively.