^{13}C MRS of Frontal Lobe at 3 Tesla Using a Volume Coil for Stochastic Proton Decoupling

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Introduction

Frontal lobe is involved in memory, emotion and higher mental functions. Most psychiatric disorders are believed to be related to dysfunction in the frontal lobe. Frontal lobe MR spectroscopy, however, has traditionally been quite challenging due to technical hurdles such as B_0 field distortion and proton decoupling that may cause safety concerns due to poor perfusion of the eyes. Recently, a new strategy has been developed that detects the primary intermediate metabolites of [2-^{13}C]glucose in the carboxylic/amide region (1, 2). Because the carboxylic/amide carbons require very low RF power for proton decoupling, frontal lobe ^{13}C MRS can be performed without RF safety concerns. Here we demonstrate, for the first time, human frontal lobe can be studied using ^{13}C MRS at 3 Tesla using optimized RF coil arrangement. A spectral deconvolution technique was developed and applied to improve spectral resolution.

Methods

RF coils: The proton coil was a short, unshielded, quadrature, high-pass, 12-leg birdcage coil (conductor width = 2.54 cm, dia. = 26.7 cm, inner length = 12.7 cm). The ^{13}C coil was a rectangular loop made with copper tape mounted on a piece of plastic tube that was curved on the axial (X-Y) plane. Its dimensions were 5 cm in the superior-inferior (SI) direction, and 9 cm in the left-right (LR) direction, respectively.

Proton decoupler: The magnet was a standard GE 3 Tesla scanner. A standalone proton decoupler was used to generate stochastic decoupling waveforms with bi-level outputs: low level pulsing during relaxation to generate NOE, and high level pulsing during data acquisition for proton decoupling. The duration of each stochastic repetition unit was 1.2 ms.

^{13}C spectroscopy: ^{13}C signals were obtained using a 500 μs 45° hard pulse, TR = 4 s, SW = 5 kHz, number of data = 1024. [2-^{13}C]glucose solution (20% w/w) was infused via an antecubital vein. FASTMAP shim was used on a cubical voxel that produced a water linewidth of ~10 or ~12 Hz for a cube of 65 or 90 cm^3 in the frontal lobe region, respectively. Cube size selection depended on the size of the frontal lobe.

RF safety: Peak RF power delivered into human head was 30 W for decoupling (duty cycle = 5%) and 1.0 W for NOE. Based on the numerically simulated SAR distribution in the frontal lobe using the same volume coil (3), the maximum local and average SARs in this study were 2.5 W/kg and 0.74 W/kg, respectively. Both were substantially below the safety guidelines established by the FDA (local SAR ≤ 8 W/kg, average SAR ≤ 3 W/kg).

Results

Figure 1 shows frontal lobe ^{13}C spectra in the carboxylic/amide region from three subjects (Figs 1a-1c) Each corresponds to a 25.5 min scan (LB = -2.0 Hz and GB = 0.3). Resonances of glutamate C5 (182.0 ppm) and C1 (175.4 ppm), glutamine C5 (178.5 ppm) and C1 (174.9 ppm), and aspartate C4 (178.3 ppm) and C1 (175.1 ppm) were detected. Glutamine C5 and aspartate C4 (0.2 ppm apart) are spectrally resolved in spectra 1b and 1c.

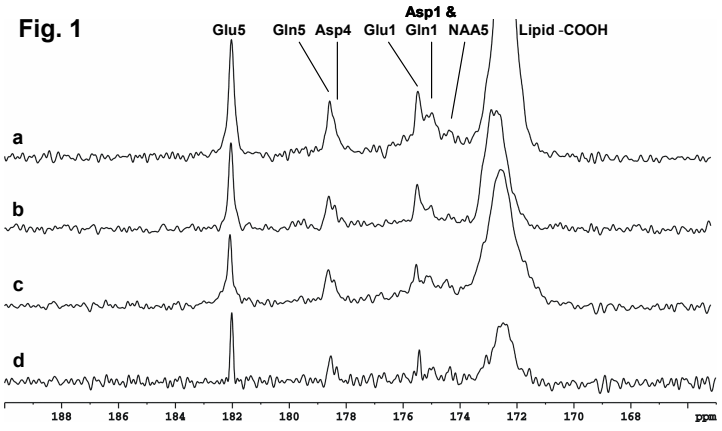
Discussion

The characteristics of the frontal lobe spectra are found to be highly similar to those of occipital lobe spectra acquired using the same volume coil for proton stochastic decoupling (2). Our approach for detecting carboxylic/amide carbons successfully solved the safety issue for frontal lobe decoupling. The remaining challenge was the previously well-characterized severe B_0 field inhomogeneity in the frontal lobe (4, 5). The B_0 field near the orbital lobe above the sinus and nasal cavity is 2-3 ppm higher than that in the superior frontal lobe. To correct this field distortion, third (fourth) order shims were often necessary. Because the clinical scanner has no third order shims, the quality of shimming and ^{13}C spectra can be limited. When the second order shims are adequate, aspartate C4 resonance can be resolved from the glutamine C5 peak, as shown in Fig. 1b and 1c. In Fig 1a, the aspartate C4 cannot be clearly distinguished from glutamine C4. Several approaches were considered to reduce the effect of strong B_0 field inhomogeneity.

(I) Because the B_0 field gradient in the frontal lobe is stronger in the SI direction than in the LR direction (5), a rectangular ^{13}C coil was used that had shorter SI direction and longer LR direction dimensions. With this approach, the strong field gradient near the orbital lobe was partially avoided by the short dimension in the SI direction, and ^{13}C signal intensity was maintained by extending the spectral volume in the LR direction.

(II) The ^{13}C coil can be shifted towards the superior frontal lobe to avoid the stronger field gradient. As the coil is shifted, it also needs to be rotated to keep the close distance to the dorsolateral and superior frontal lobes. As the result of the rotation, the primary B_1 field is not perpendicular to the B_0 field, which leads to less coil efficiency and SNR reduction.

(III) Lineshape distortion due to field inhomogeneity may be removed by reference deconvolution (6). The peak of glutamate C5 is well isolated and has relatively high intensity; it can be used as an internal reference for spectral deconvolution. Spectrum 1c was reprocessed with deconvolution and the deconvolved spectrum (LB = -2.0 Hz and GB = 0.3) is shown in Fig. 1d. Spectral resolution was improved and the glutamine C5 and aspartate C4 peaks were better resolved. This method may be applied when the original spectrum has adequate SNR and spectral resolution.



Conclusion

Proton decoupled ^{13}C MRS spectra has been safely acquired from the frontal lobe of the human brain with limited high-order shim capability. Resonances of glutamate C5 and C1, glutamine C5 and C1, and aspartate C4 and C1 were detected. ^{13}C surface coil arrangement and spectral deconvolution may be used to partially reduce the effects of strong B_0 field inhomogeneity in the frontal lobe.

References

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