Fast 4D Metabolite Mapping of Hyperpolarized 13C Compounds using Multiple Echo 3D FIESTA

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OBJECTIVE: The objective of this work is to develop a technique which will allow repeated measurements of spatial (3D imaging) and spectral (1D chemical-shift) distributions following administration of a hyperpolarized 13C substrate in order to determine spatially localized metabolic kinetics (e.g. spatial distribution of tumor metabolism of 13C-pyruvate to 13C-lactate).

BACKGROUND: Reeder et. al [1] first demonstrated the ability to derive high spatial resolution chemical-shift images from multiple sequential gradient echoes acquisitions at echo times shifted by Δt. Recently Wieben et. al.[2] proposed a much faster method for acquiring both the spatial and spectral information in one scan using a multiple-echo 2D balanced SSFP (FIESTA) imaging technique. The Nyquist frequency (N_f) for this technique is determined by the echo spacing, Δt, where $N_f=1/(2\Delta t)$, and the spectral resolution (Δf) is determined by $\Delta f = 1/(N \Delta t)$, where N is the number of acquired echoes, The multiple-echo 2D FIESTA technique is fast, has relatively high spatial resolution, and is able to adjust the number of echoes (N) and the echo spacing (Δt) to provide the desired spectral resolution. We have implemented a multiple gradient echo 3D FIESTA technique in order to provide the increased SNR necessary for imaging hyperpolarized ^{13}C labeled compounds (products and substrates) at low concentration.

MATERIALS and METHODS: All ^{13}C imaging was performed in a transmit/receive ^{13}C surface coil designed and built in our laboratory. All imaging was performed on a 1.5 T General Electric Signa MR scanner operating with version 9.1 software. The manufacturer's standard 3D FIESTA pulse sequence was modified to allow multi-nuclear and multiple-echo imaging (ME-3DFIESTA). A phantom consisting of a sphere containing ^{13}C-acetate and a vial containing ^{13}C-2-hydroxyethylacrylate (280 Hz chemical shift) were placed on the ^{13}C surface coil. ME-3DFIESTA imaging was performed with a 16 x 64 x 64 matrix giving isotropic 7 mm spatial resolution, BW=62.5 MHz, 12 echoes, 1.68 ms echo spacing, Δt=49.6 Hz, N_f=297 Hz, and TR=21.2 ms for a 25 second scan time. In a second experiment multiple ME-3DFIESTA acquisitions were also obtained on a syringe containing 50 mM of both ^{13}C-hydroxyethylpropionate and ^{13}C-cis-fumarate simultaneously hyperpolarized using the PASADENA technique[3,4]. The parameters for this acquisition were the same as above except a TR of 14.5 ms, acquisition of 8 echoes with echo spacing of 1.34 ms, and an imaging time of 17 seconds. The spectral data was reconstructed with the technique reported by Leupold et. al.[5]

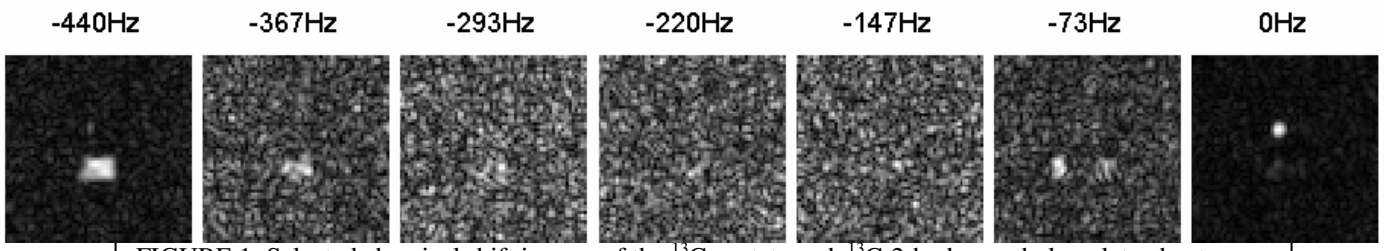
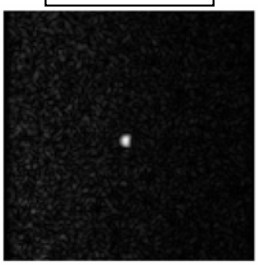


FIGURE 1: Selected chemical shift images of the ^{13}C-acetate and ^{13}C-2-hydroxyethylacrylate phantom.

RESULTS: Selected chemical shift images calculated from imaging the ^{13}C-acetate and ^{13}C-2-hydroxy-ethylacrylate phantom using the ME-3DFIESTA pulse sequence are shown in Figure 1. The chemical shift images in Figure 1 demonstrate the ability of the ME-3DFIESTA to provide metabolite images with the correct chemical shifts under static conditions. The first echo spatial image of the syringe containing simultaneously hyperpolarized ^{13}C-hydroxyethylpropionate and ^{13}C-cis-fumarate is shown in Figure 2. Selected chemical shift images of this phantom are shown in Figure 3 demonstrating the ability of the ME-3DFIESTA technique to provide spatial and spectral information of hyperpolarized ^{13}C-labeled substrates and products in a timely manner.

FIGURE 2



CONCLUSION: We have demonstrated the feasibility of implementing a fast multiple gradient echo 3D FIESTA technique for the rapid measurement of spatial location and chemical shift of hyperpolarized ^{13}C-labeled substrates and products.

REFERENCES: [1]Reeder et al., MRM 51, 35-45, 2004. [2] Wieben et al. Proceedings of the ISMRM, p. 2386, 2005 [3]Bhattacharya et at., Proceedings of the ISMRM, p 171, 2005 , [4]Bhattacharya et. al. 2005) *MAGMA*, 18.5 [5] Leupold et at., Proceedings of the ISMRM, p 102, 2005.

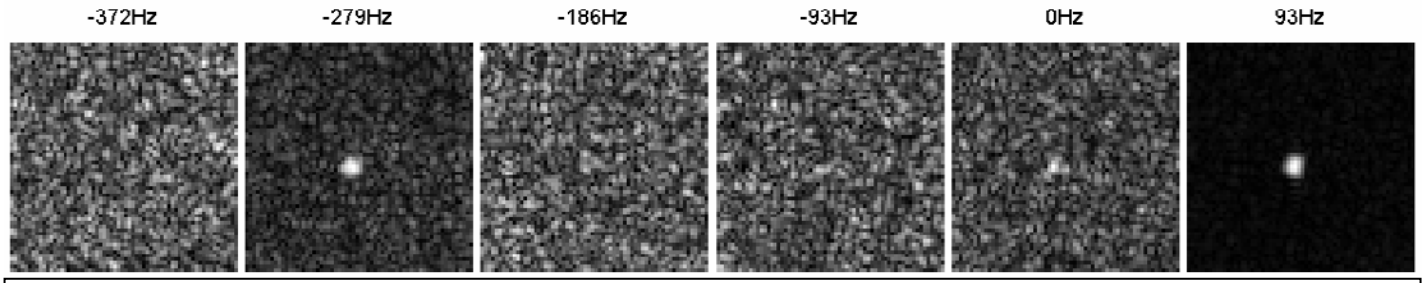


FIGURE 3: Selected chemical shift images of simultaneously hyperpolarized ^{13}C- hydroxyethylpropionate and ^{13}C-cis-fumarate.