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Parallel MRI Acceleration of Dynamic and High Resolution Hyperpolarized ^{13}C MRI

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Introduction

- Due to limited life times of pre-polarised spins (T_1 ≈ 1min for [1-^{13}C]-pyruvate at 3T) imaging of hyperpolarized ^{13}C-enriched substrates requires fast imaging

- Traditional use of field gradients for spatial encoding is very slow

- Parallel MRI can acquire images faster with little to no loss in SNR
  (Lee, et. Al. MRM 2006 **55**:1132)

Purpose

To demonstrate the feasibility and advantages of parallel MRI acceleration at high spatial and temporal resolutions after injection of a hyperpolarized ^{13}C-enriched substrate

Methods

Hyperpolarized Substrate Preparation

- [1-^{13}C]-pyruvic acid (CIL, Cambridge MA) with 15mM OX63 trityl radical (Oxford Instruments, Abingdon UK) and 1mM Dotarem (Guerbet)
- Pyruvic acid mixture was polarized using a HyperSense DNP polarizer (Oxford Instruments, Abingdon UK)

Methods

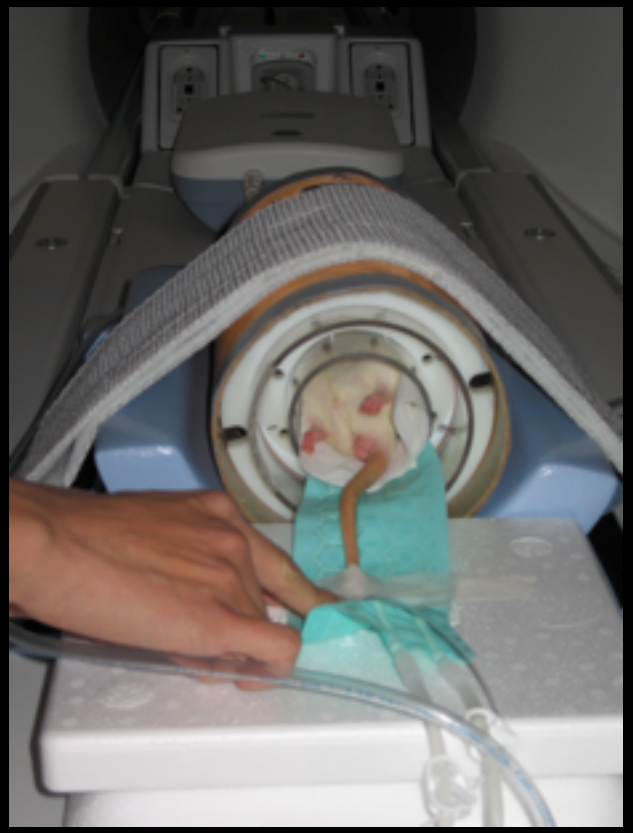
Animal Preparation

- Approval was obtained from the institutional Animal Use Subcommittee
- Normal Sprague-Dawley rats were anesthetized with isofluorane
- 2.5mL of hyperpolarized [1-^{13}C]-pyruvate (80mM, pH=7.8) was injected into the tail vein over 13 seconds

Methods

RF Coils

- Custom dual tuned RF coil (^{1}H transmit/receive, ^{13}C transmit)
- Custom 8 coil array designed for ^{13}C at 3.0T (MR750, GE Healthcare, Waukesha, WI, see poster #1489)



Methods

^{1}H MR Imaging

- ^{1}H images were collected using a spoiled gradient sequence (SPGR)

  TR=4.3ms, TE=1.5ms, FOV=200x200mm, 5mm slice thickness, 5mm slice spacing, 128x128 matrix

Methods

Dynamic ^{13}C MR Imaging

- Fully gradient-encoded datasets were collected beginning 8s after the start of [1-^{13}C]-pyruvate injection.

- 10 coronal images collected at 2s intervals using 2D fast gradient recalled echo (FGRE) sequence

  TR=10.7ms, TE=4.8ms, flip angle=5^{o}, bandwidth=±4KHz, FOV=200x200mm, 200mm slice thickness, 64x64 matrix, acquisition time=0.58s/image

Methods

Dynamic ^{13}C Image Reconstruction

- Twelve, fully sampled lines at centre of k-space were used to determine coil sensitivities

- Generalized encoding matrix reconstruction with:
  Sub-sampling to simulate outer reduction factors (ORF) of 2, 3, and 4 and net reduction factors (R) of 1.7, 2.2 and 2.6 respectively

Methods

High Resolution ^{13}C MR Imaging

- Fully gradient encoded images collected at 8 and 15s post-injection of [1-^{13}C]-pyruvate using 2D FGRE sequence

  TR=11.2ms, TE=5.0ms, flip angle=10^{o}, bandwidth=±8KHz, FOV=180x72mm, 200mm slice thickness, 128x52 matrix, acquisition time=0.58s/image

Methods

High Resolution ^{13}C Image Reconstruction

- Sixteen, fully sampled lines at centre of k-space were used to determine coil sensitivities

- Generalized encoding matrix reconstruction with:

  Sub-sampling to simulate outer reduction factors (ORF) of 2, 3, and 4 and net reduction factors (R) of 1.5, 1.9 and 2.1 respectively

Methods

3-dimensional ^{13}C Imaging

- Fully gradient encoded images collected at 14 seconds post-injection of [1-^{13}C]-pyruvate to capture [1-^{13}C]-pyruvic acid in the vasculature and major organs (heart and kidneys)

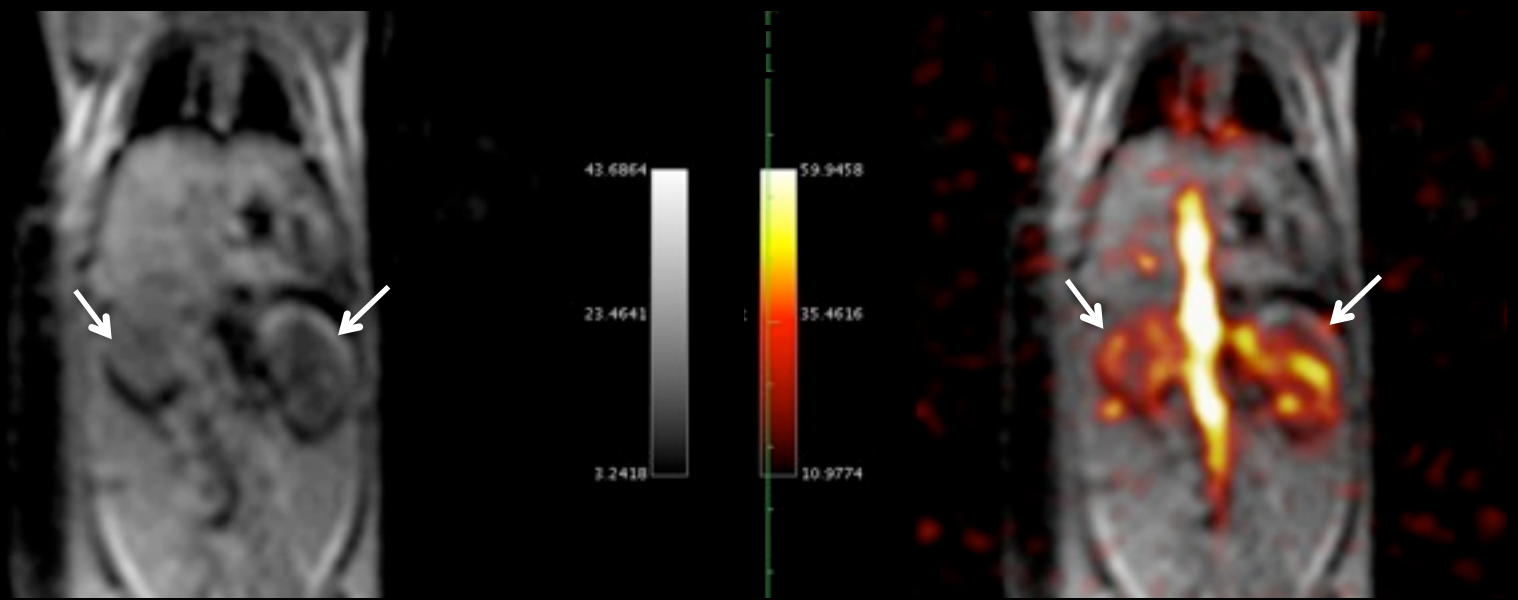
- 3D FGRE sequence

  TR=12.3ms, TE=5.0ms, flip angle=4^{o}, bandwidth=±4KHz, FOV=200x100mm, 5mm slice thickness, 64x64 matrix

Results

Fig 1:

A) ^{1}H SPGR image. B) Overlay of ^{13}C image on the proton image shown in A. Arrows point to kidneys.



Results

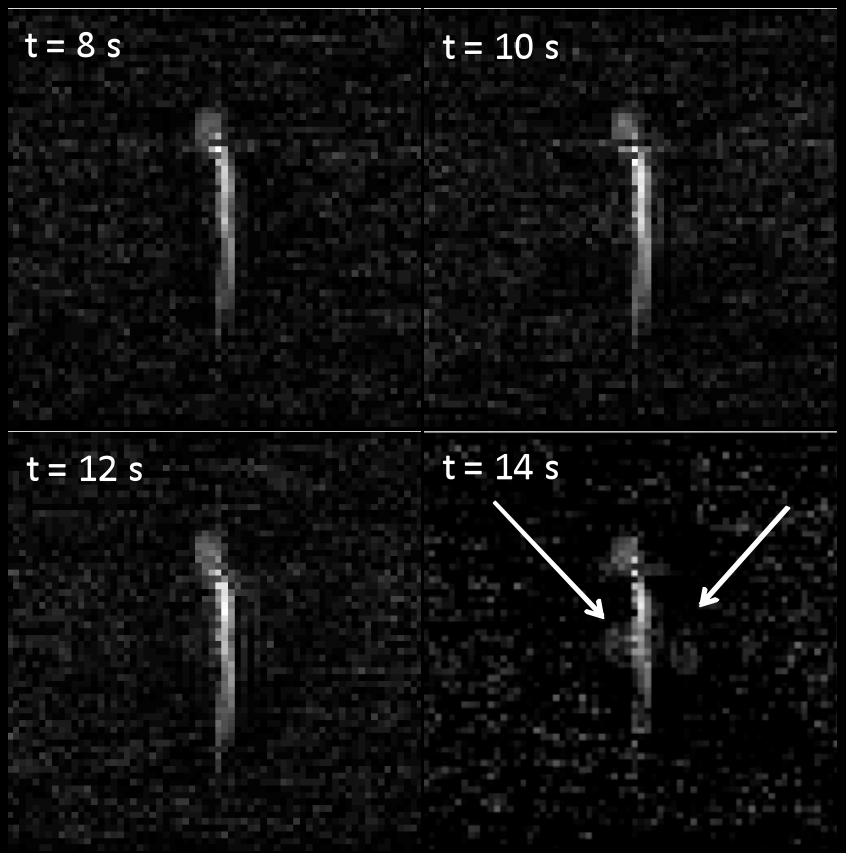


Fig 2:

- PMRI accelerated (R=1.7) projection images starting 8s following injection of 80mM [1-^{13}C]-pyruvate.
- In-plane resolution=2.8mm, effective acquisition time=0.41ms, acquisition interval=2.0s.

- Flow of [1-^{13}C]-pyruvate into the kidneys is apparent at 14s post-injection (arrows).

Results

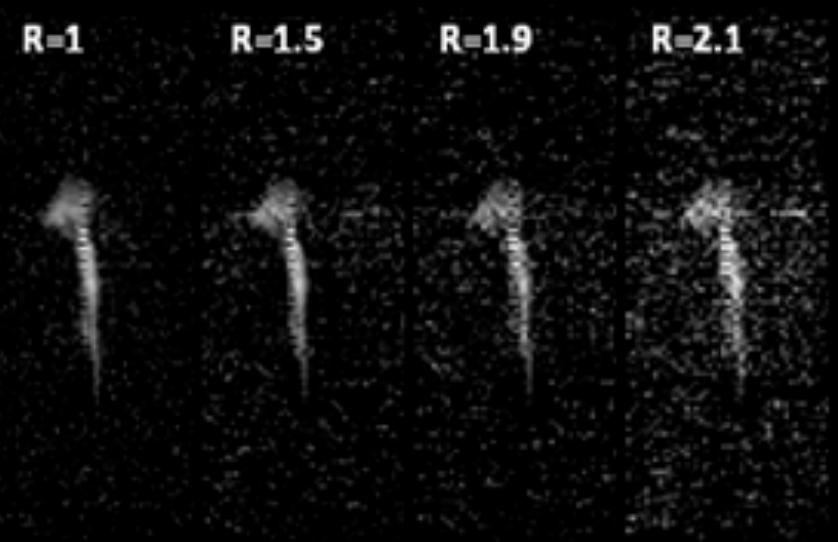


Fig 3:

- PMRI accelerated projection images acquired 8s following injection of 80mM [1-^{13}C]-pyruvate.

- k-space data were decimated to obtain net reduction factors as shown (R=1=no acceleration).
- In plane resolution =1.4mm, effective acquisition times = 0.58ms, 0.39ms, 0.31ms, and 0.28ms

Results

Fig 4:

Volume rendering of 3-dimensional ^{13}C images

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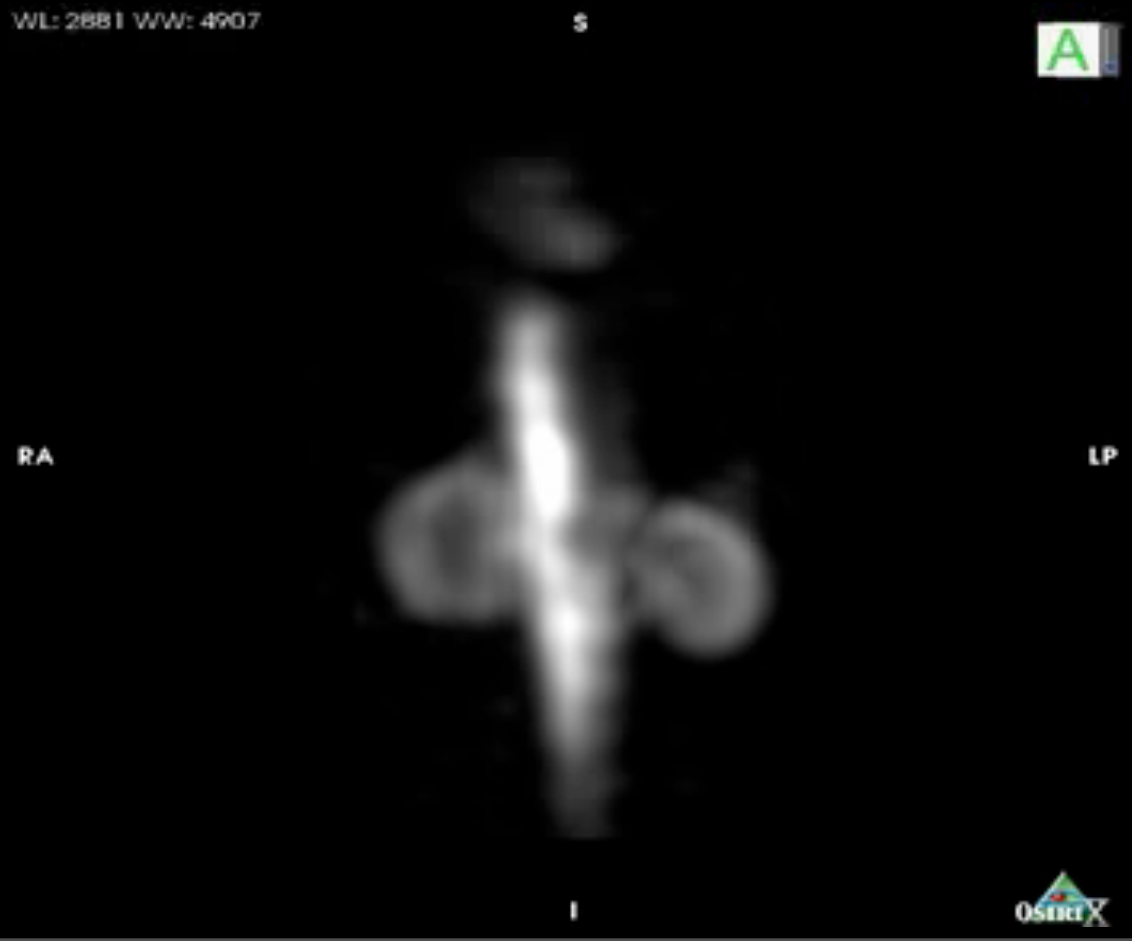
Volume rendering of 3-dimensional ^{13}C images



Discussion

- 1D reduction factors up to 2 were achieved before increasing g-factor caused excessive SNR loss.
- Artificial Decimation:
  - Led to significant under estimation of achievable SNR.
  - In truly accelerated images, fewer phase encodes are required allowing larger flip angles, and increased SNR.
- Variable flip angle schemes may significantly increase SNR.

Conclusion

- Self-calibrated parallel MRI was used to obtain dynamic and high resolution images of a small animal injected with hyperpolarized [1-^{13}C]-pyruvate.

- ^{13}C images were obtained using a novel 8-channel receive array.

Acknowledgements

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