Accelerated Diffusion-Weighted Hyperpolarized $^{129}$Xe Gas Lung MRI

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Declaration of Relevant Financial Interests and/or Relationships

A. Ouriadov and all co-authors:
We have no relevant financial interests or relationships to disclose with regard to the subject matter of this presentation.
Thermal Polarization

- Nuclei with spin $= \frac{1}{2}$ are placed in an externally applied magnetic field.
- Polarization ($P$) arises from a population difference in energy levels of spin $= \frac{1}{2}$ nuclei.

$$P = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$$

$$E = +\frac{1}{2} \gamma \hbar B_0$$

$$E = -\frac{1}{2} \gamma \hbar B_0$$
Spin-Exchange Optical Pumping

- Rubidium electrons are optically pumped into an excited state using circularly polarized laser light.
- The electronic polarization of Rb is transferred to the noble gas nuclei via collisions.
Spin-Exchange Optical Pumping

$^{129}$Xe Polarizer, Polarean, USA

Polarization: 30%

Cryogens required for operation

Production Rate: ~800ml/hour
$^1$H MRI vs Hyperpolarized Gas MRI
Hyperpolarized Gas MRI

Helium-3

Xenon-129

$^{129}$Xe MRI Hardware
Single Breath-hold Isotropic $^{129}$Xe MRI

Isotropic $^{129}$Xe MRI in a healthy volunteer provides sufficient SNR for reconstructed coronal and axial planes

Barker A, et al., ISMRM 2019
Emphysema: Pathology

Evaluating Emphysema

- Spirometry and Plethysmography
- Computed Tomography
- Diffusion-Weighted (DW) Hyperpolarized Gas MRI
DW Hyperpolarized Gas MRI

Healthy

Emphysema

$ADC = \frac{r^2}{2t}$

$ADC = \text{apparent diffusion coefficient}$

$r = \text{distance the helium atoms diffuse}$

$t = \text{diffusion time}$
$S(b) = S_0 \exp(-bADC)$

$b = 1.6 \text{ s/cm}^2$

A stretched exponential method\(^3\) (SEM) combined with under-sampling (compressed sensing) in the imaging and diffusion directions\(^4\) was proposed for the evaluation of hyperpolarized gas multiple b-value diffusion-weighted MRI.

The major advantage of this method is the possibility to significantly speed up the data acquisition using acceleration factors (AF) between 7 and 10.\(^4\)

Research Objective

To develop the accelerated SEM-based $^{129}$Xe MRI approach and generate hyperpolarized gas MRI-based emphysema biomarkers in a small group of young healthy volunteers and Alpha-1 Antitrypsin Deficiency subjects.

Research Hypothesis

Accelerated (7 folds faster) methods can be developed to provide whole lung hyperpolarized gas MRI-based emphysema biomarkers including static-ventilation, $T_2^*$, ADC and morphometry maps in a single 16 sec breath-hold.
## Methods: MRI Protocol

### 3.0 T Discovery MR750 (GEHC)

<table>
<thead>
<tr>
<th>Pulse Sequence Parameters</th>
<th>Hyperpolarized $^{129}$Xe MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accelerated 2D Gradient Echo DW</strong></td>
<td>Matrix Size = 128x20, Acceleration Factor = 7</td>
</tr>
<tr>
<td>Short-TE/TE/TR/FA/BW = 2ms/10ms/5ms/4°/31.25kHz</td>
<td>Diffusion time ($\Delta$) = 5.2ms</td>
</tr>
<tr>
<td>$b$-values = 0, 0, 12, 20, 30, 45.5 s/cm$^2$</td>
<td>FOV = 40x40cm$^2$, 8 slices, 30 mm slice thickness</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Dose</th>
<th>CMRS flexible transmit/receive chest coil</th>
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</thead>
</table>

| Coil | CMRS flexible transmit/receive chest coil |
Methods: Image Analysis

Diffusion Attenuated MR Signal in SEM:

\[ S(b) = S_0 \exp(-b \cdot DDC)^\alpha, \]

where DDC = diffusivity, \( \alpha \) = heterogeneity index; and mean diffusion length \( (L_{mD}) = (2 \Delta <DDC>)^{1/2} \)

The SEM was extended\(^4,^5\) to provide clinically-relevant biomarkers of emphysema, such as mean linear intercept \( (L_m) \)^6 for \(^{129}\)Xe:

\[ L_m = -562 \mu m + 4.3 \cdot L_{mD} \cdot \sqrt{\frac{D_{0\text{He}}}{D_{0\text{Xe}}} \Delta_{\text{He}}}{\Delta_{\text{Xe}}} \]

\[ D_{0\text{He}} = 0.83 \text{ cm}^2/\text{s}^7 \]
\[ D_{0\text{Xe}} = 0.22 \text{ cm}^2/\text{s}^7 \]
\[ \Delta_{\text{He}} = 1.46 \text{ ms} \]
\[ \Delta_{\text{Xe}} = 5.2 \text{ ms} \]

\(^5\)COuriadov. et al. ISMRM, (2016).
Methods: Pulse Sequence

Time

TE=10ms

G_x

G_y

G_z

Pulse

Time

TE=2.0ms

b = 0
TE=2.0ms

b = 0

b = 12

b = 20
TE=10ms

b = 30

b = 45.5

Image

K-space
Results: Accelerated $^{129}$Xe MRI

Results: Accelerated $^{129}$Xe MRI

Conclusions

- Accelerated $^{129}$Xe MRI provides a way to generate alveolar morphometry estimates to regionally characterize emphysema and airspace enlargement in patients with AATD in a single 16 sec breath-hold scan.

- The Signal-to-Noise Ratio (35-40) of the short-TE image was more than adequate for the calculation of the Ventilation Defect Percentage which may be simultaneously generated with $T_2^*$, ADC and $L_m$ values in a single rapid breath hold.

- This is the first in patient demonstration of this acceleration (7x) method for $^{129}$Xe and it suggests that the acceleration factors of 10 fold are possible. It will help retain resolution, maintain high number of b-values.

_Ouriadov A, et all, ISMRM 2019_
Translating $^{129}$Xe MRI Across Canada

London ON: Robarts Research Institute
Toronto ON: The Hospital for Sick Children
Hamilton ON: Firestone Institute for Respiratory Health
St. Joseph’s Healthcare
Thunder Bay ON: Thunder Bay Regional Research Institute
Montreal QC: CHU Sainte-Justine
Université de Montreal
Vancouver BC: The Institute of Heart and Lung Health
St. Paul’s Hospital