# MR imaging of hyperpolarized $^{129}$Xe and $^{3}$He: sequential *in vivo* lung-imaging of the same subject and simultaneous imaging of phantoms

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## Introduction

During the last ten years hyperpolarized $^{3}$He (HpHe) MR lung-imaging has advanced considerably. Due to the lower MR signal obtained from hyperpolarized $^{129}$Xe (HpXe) ($\gamma_{He}/\gamma_{Xe}$ ~ 2.8; 26% nat. abundance of $^{129}$Xe versus isotopically pure $^{3}$He) considerably fewer human MR studies with HpXe have been performed up to now. However, due to the solubility of xenon in blood and tissue HpXe-MRI might be of additional value for lung diagnosis. Whereas HpHe allows to assess fast ventilation dynamics [1], lung physiology at high spatial resolution [2] and lung microstructure [3] very well, only HpXe allows to study the kinetics of gas diffusion through the alveolar-capillary membrane using MR techniques [4,5]. Additionally, due to the large differences in the diffusivity of helium and xenon images, of the lungs might show differences. A first attempt to study such differences was made by Blümler et al. [6] who performed simultaneous $^{3}$He/$^{129}$Xe imaging of a glass tube filled with HpHe and HpXe using a small bore high field (7T) scanner. We are aiming at simultaneous $^{3}$He/$^{129}$Xe MR lung-imaging using a human whole body MR scanner. To show the feasibility of simultaneous $^{3}$He/$^{129}$Xe lung imaging with the available apparatus separate *in vivo* lung-images using HpXe and HpHe on the same healthy volunteer were acquired on different days. Furthermore a simultaneous $^{3}$He/$^{129}$Xe-sequence was implemented and tested on glass bulbs filled with HpHe and HpXe.

## Methods

$^{129}$Xe (natural abundance) was polarized by spin-exchange optical pumping [7] using a home-built flow system [8]. One liter of HpXe gas (normal conditions) was accumulated as ice in the LN trap and thawed to fill a detachable Tedlar$^{TM}$ bag (GSTP001-0707, JENSEN INERT, Coral Springs, USA) used for in vivo studies or a detachable glass bulb for phantom measurements. $^{129}$Xe polarizations of 8-15% were routinely achieved. Additionally a $^{3}$He polarizer, being under construction and operating in a batch mode, presently allows to produce about 0.3 liter HpHe at polarizations of up to 5%.

All MR measurements were performed on a 3 tesla scanner (MedSpec 30/100, BRUKER BIOSPIN MRI, Ettlingen, Germany) using home-built transmit-receive surface coils (30x20 cm$^2$) tuned to the $^{3}$He/$^{129}$Xe frequencies of 95.47 MHz and 34.66 MHz, respectively.

All hyperpolarized gas images were acquired by a low flip angle gradient echo sequence (FOV 51.2x51.2 cm$^2$, 128x128 matrix for the in vivo measurements, 256x256 matrix for the phantom measurements) sampling the *k*-space lines in a centered mode. RF-excitation and $T_1$-relaxation causes the various *k*-space lines to be sampled at different polarizations of the gas and hence a smearing of the image along the phase encoding direction normally appears. To reduce this effect an adequate weighting of the signals of the different *k*-space lines was performed before image processing. For illustration purposes $^{1}$H images (same FOV, 256x256 matrix) were superimposed with the hyperpolarized gas *in vivo* images.

For *in vivo* lung imaging two identical surface coils were placed on the front and back of the volunteer's chest. For $^{129}$Xe-imaging the transmit pulse was applied to the coils and the $^{129}$Xe signals from the coils received via a differential combiner. For $^{3}$He-imaging a two channel transmit-receive sequence was used circumventing the loss in signal by the differential combiner. After inhaling the hyperpolarized gas the volunteer held breath during the acquisition of three to four slices (12-16 s).

For the simultaneous $^{3}$He/$^{129}$Xe phantom imaging one Xe-coil (bottom) and one He-coil (top) was used loaded by a tissue equivalent phantom (5cm thick) between both coils. At one end of the longer sides of the coils the loading phantom gave room for the glass bulbs filled with hyperpolarized gases. A two channel sequence was programmed where the *k*-space lines of both species were sampled interleaved.

## Results

The $^{3}$He and $^{129}$Xe *in vivo* lung-images of comparable slices (Fig. 1, 2) exhibit about the same signal intensities from the hyperpolarized gases. Although $P_{Xe}/P_{He}$~3 the $^{129}$Xe-image has a slightly lower SNR compared to the $^{3}$He-image resulting from the lower MR signal obtained from HpXe. It appears that the $^{3}$He-image shows more clearly the lung anatomy especially apparent in the caudal region of the lungs. This might arise from the lower diffusivity of xenon, but must be clarified by simultaneous $^{3}$He/$^{129}$Xe lung-imaging, after inhalation of a mixture of HpHe and HpXe.

For testing the sequence programmed for simultaneous $^{3}$He/$^{129}$Xe imaging, two bulbs of HpHe (#1, #3 in Fig. 3) and two bulbs of HpXe (#2, #4) were positioned between both transmit-receive coils where one of the $^{3}$He ($^{129}$Xe) bulbs had a high gas pressure (p>1.5 atm) and the other one a lower gas pressure (p<0.8 atm). Within the shielded room of the scanner the bulb with the high HpHe pressure (#1) and the bulb with the low HpXe pressure (#4) were connected by a glass manifold that could be evacuated. Just before starting image acquisition the valves of bulbs #1 and #4 were opened so that HpHe could stream from bulb #1 into bulb #4. In the two images obtained, two bulbs with HpXe and three bulbs with HpHe could clearly be seen. For illustration purpose these images are superimposed in Fig. 3. The higher signals on the top (bottom) of the images of the bulbs result from the inhomogeneous $B_1$-field distribution of the transmit-receive $^{3}$He ($^{129}$Xe) coil lying on top (beneath) the bulbs. All bulbs showing HpHe signals additionally exhibit higher intensities close to the bulb wall. This effect arises from the partially restricted diffusion of the gas close to the vessel walls whereas the gas in the bulk can freely diffuse out of the imaged slice during data acquisition resulting in signal loss.

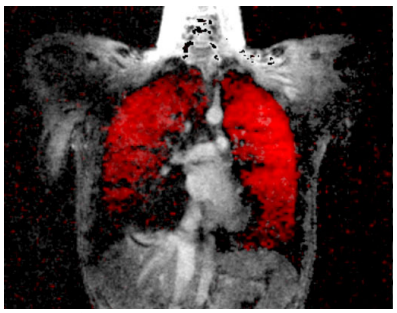

Figure 1: $^{129}$Xe (red) lung image ($P_{Xe}$~10%, slice thickness 20 mm) superimposed on $^{1}$H (white) chest image.

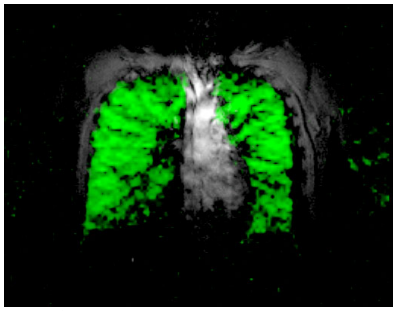

Figure 2: $^{3}$He (green) lung image ($P_{He}$~3.4%, slice thickness 25 mm) superimposed on $^{1}$H (white) chest image.

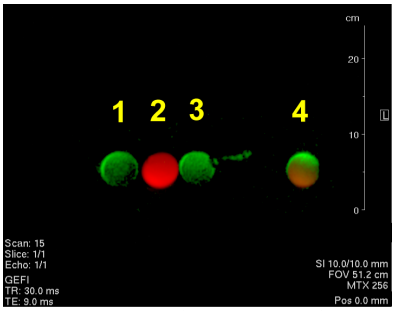


Figure 3: Combined $^{129}$Xe (red) and $^{3}$He (green) image (slice thickness 10 mm) of four glass bulbs (inner diameter ~5 cm) filled with HpXe and HpHe.

## Discussion

With the apparatus available to us we can perform sequential $^{3}$He/$^{129}$Xe human lung imaging as well as simultaneous $^{3}$He/$^{129}$Xe imaging using smaller amounts of hyperpolarized gases. With further improvements in gas-production and –storage we will be able to perform simultaneous $^{3}$He/$^{129}$Xe human lung-imaging for studying differences in image contrast.

## References

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