Imaging Emphysema – 3-Helium MR Imaging

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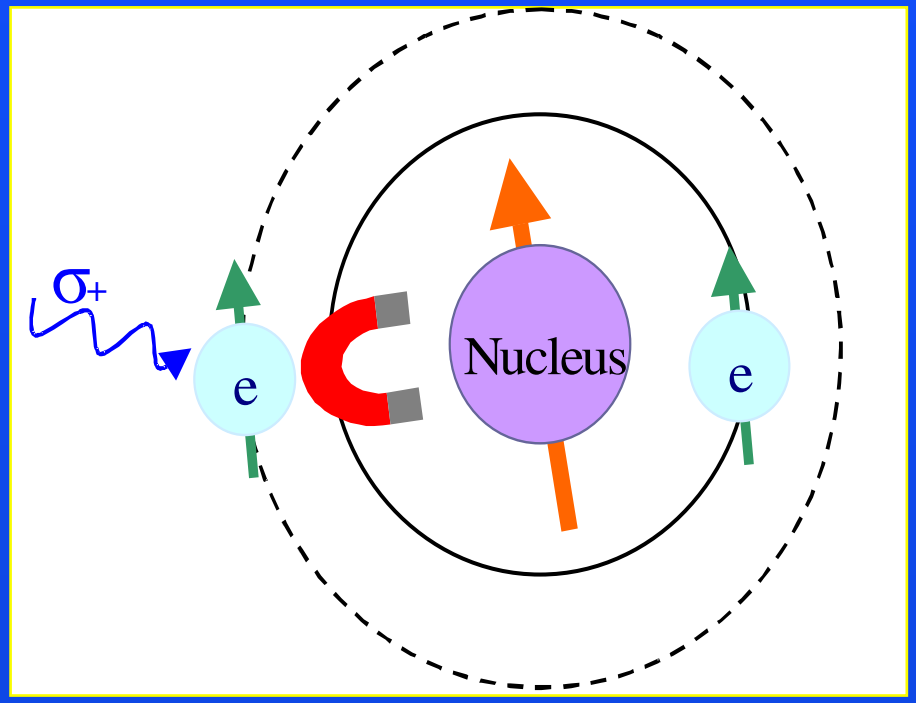
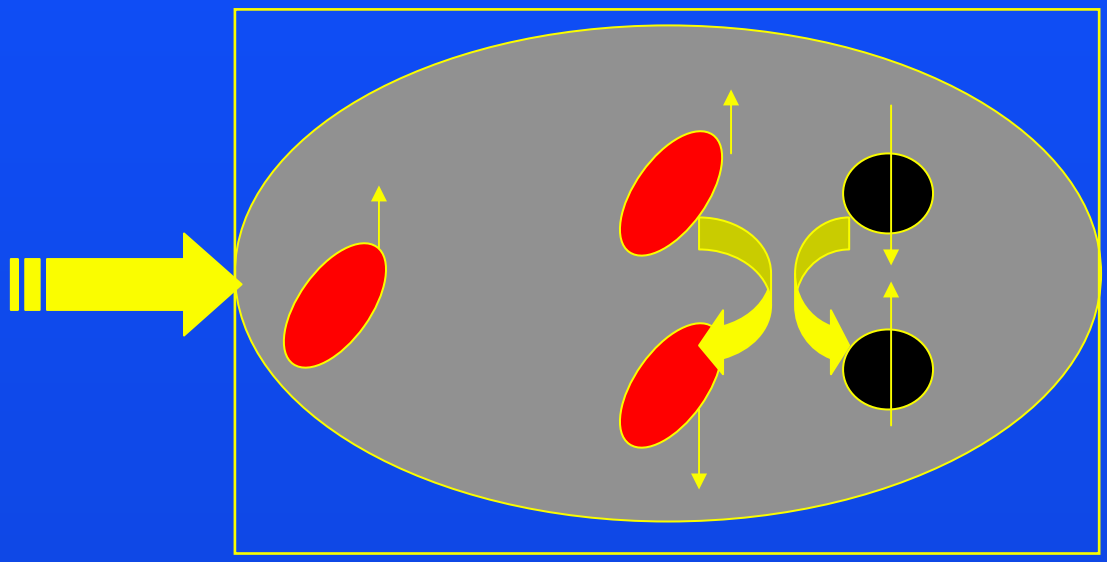
MRI of COPD

* Proton MRI is capable for assessment of cardiac anatomy and function (pulmonary hypertension), diaphragmatic pump and oxygen enhanced imaging for ventilation assessment (next speaker)
* Hyperpolarized gas MRI is capable of assessing ventilation, oxygen uptake and lung microstructure.

Polarization of 3-He: two methods



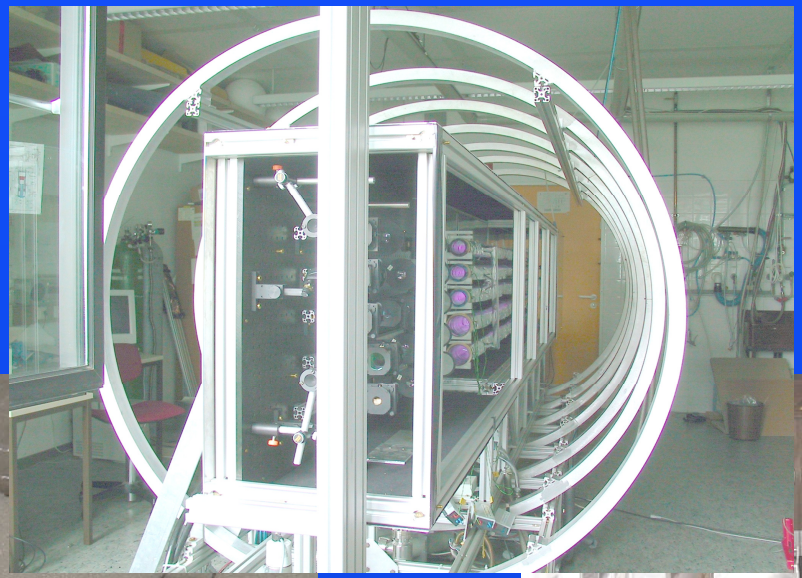
Direct optical pumping



Metastable spin exchange (Rb-He)

Local production of hyperpolarized 3-Helium

HP 3-Helium gas from Mainz to Sheffield (by airfreight)



Van Beek et al. Eur Radiol 2003

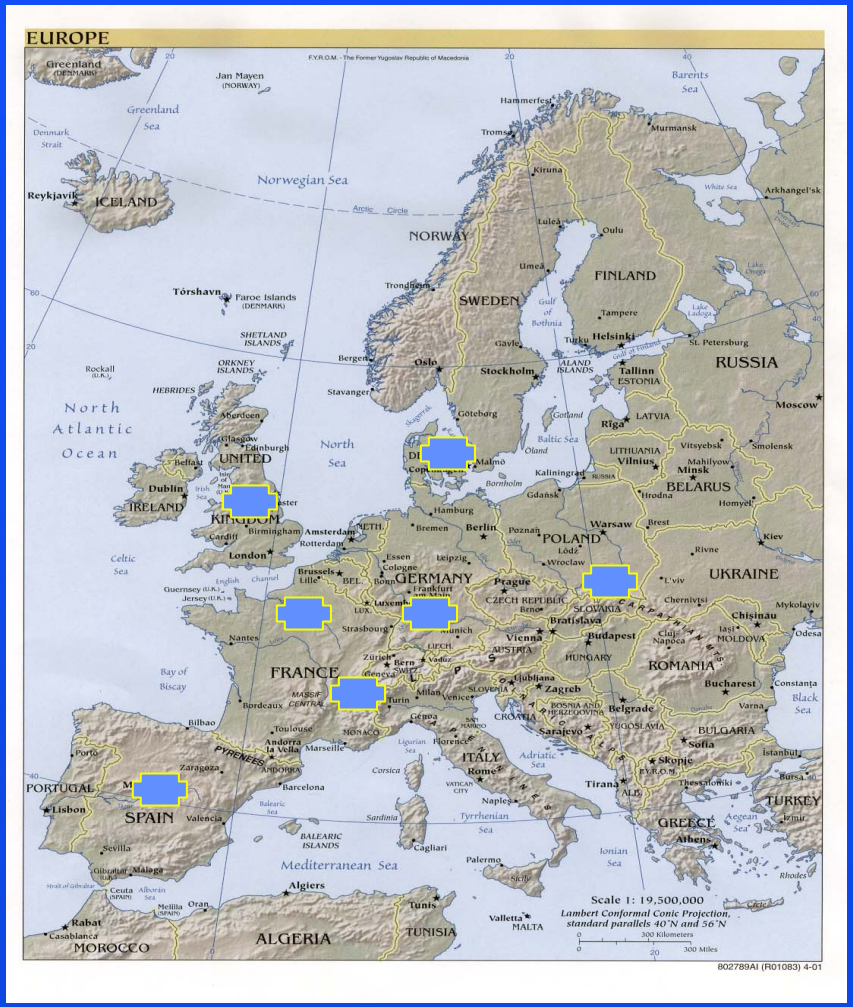
Types of sequences and information on lung function

* Static ventilation image: ventilation distribution
* Apparent Diffusion Coefficient: small airway size
* Dynamic ventilation imaging: inflow pattern of gas into airways
* Partial oxygen tension: efficiency of regional oxygen uptake

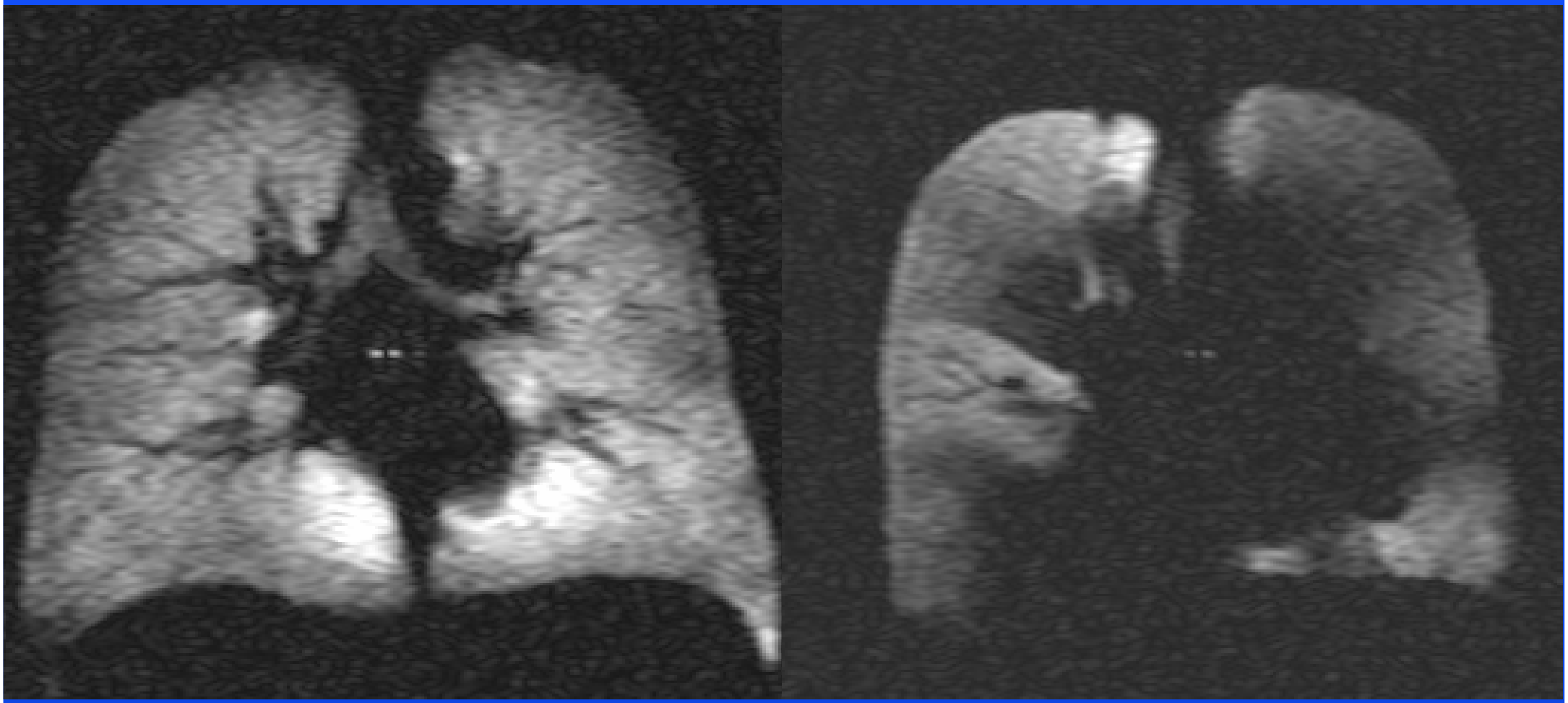
PHIL project

- Multidisciplinary consortium (7 sites in France, Spain, Germany, Poland, Denmark and Great Britain) was set up.
- Part 1: improve production, storage and distribution of hyperpolarized 3-He gas (Paris, Mainz)
- Part 2: use hyperpolarized 3-He in study of animal models of emphysema (Lyon, Madrid, Krakow)
- Part 3: perform a clinical multi-center study in normal volunteers and patients with emphysema (Mainz, Sheffield, Copenhagen)

www.phil.ens.fr



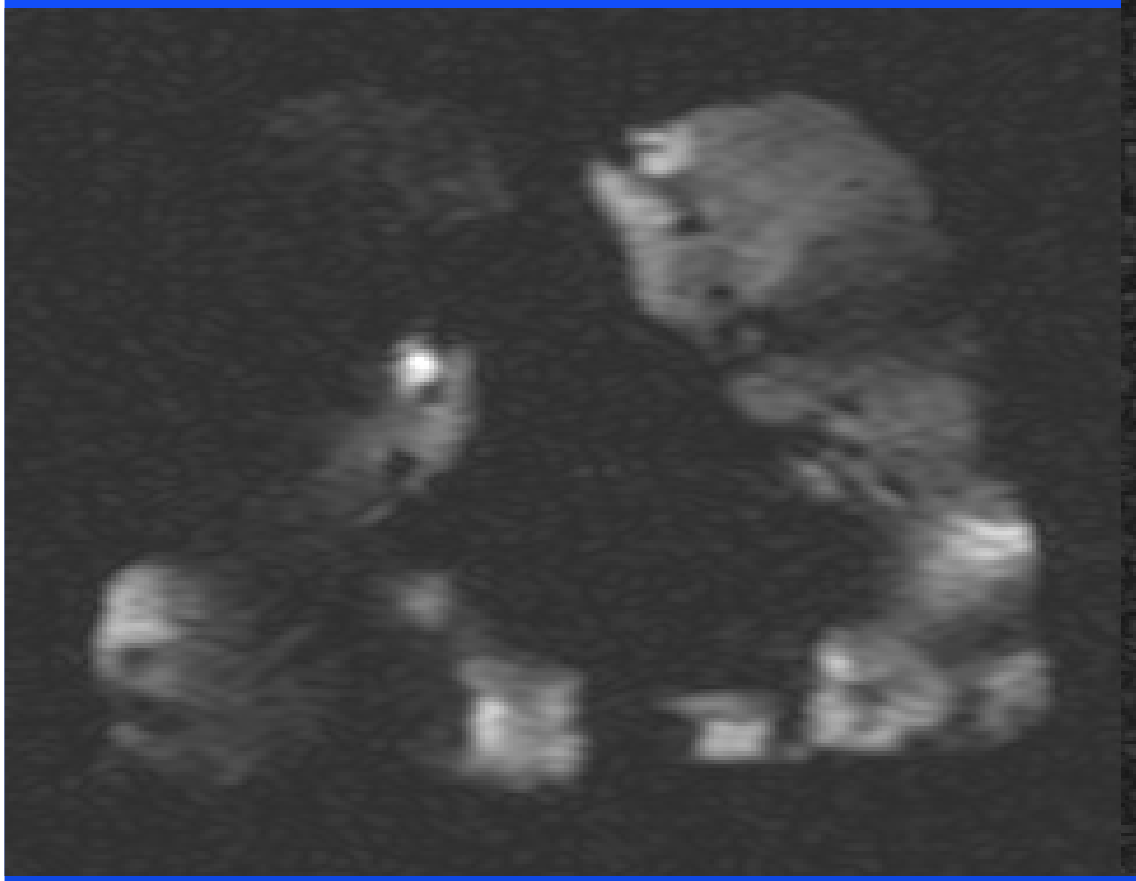
Normal vs COPD

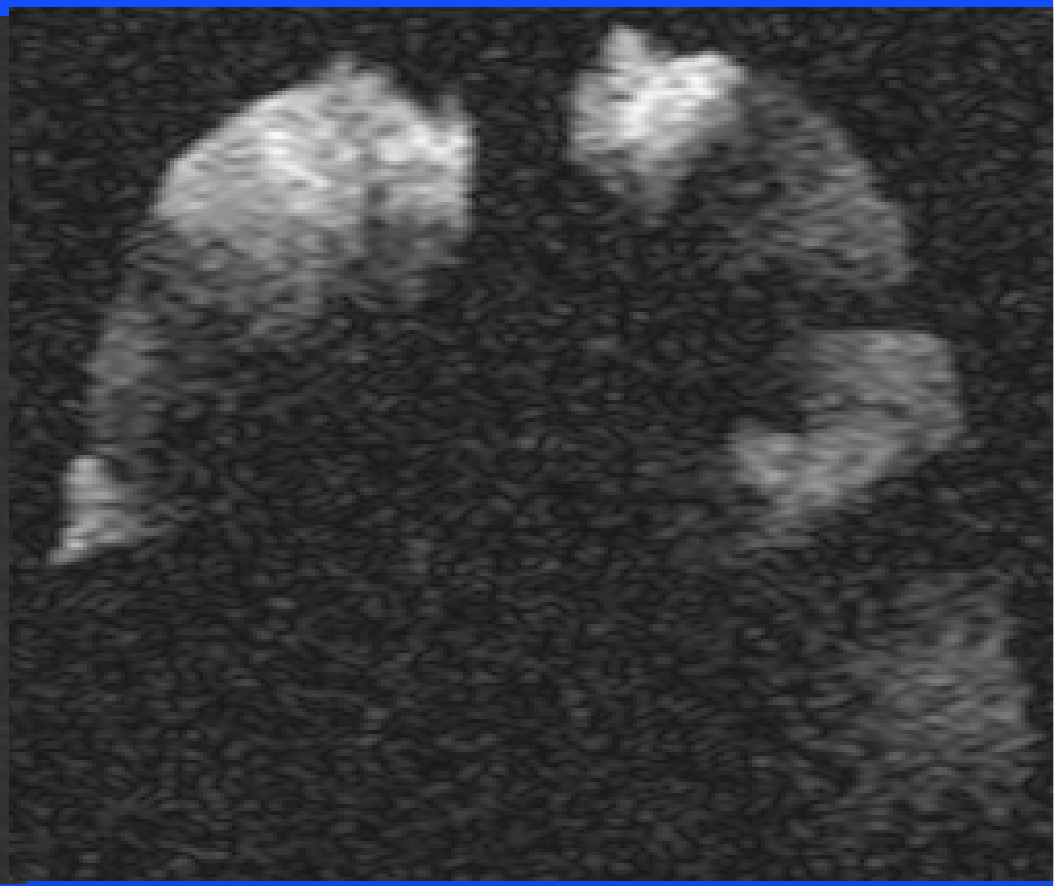


Score 1 normal

Score 2 mild

^{3}He-MRI: Scores

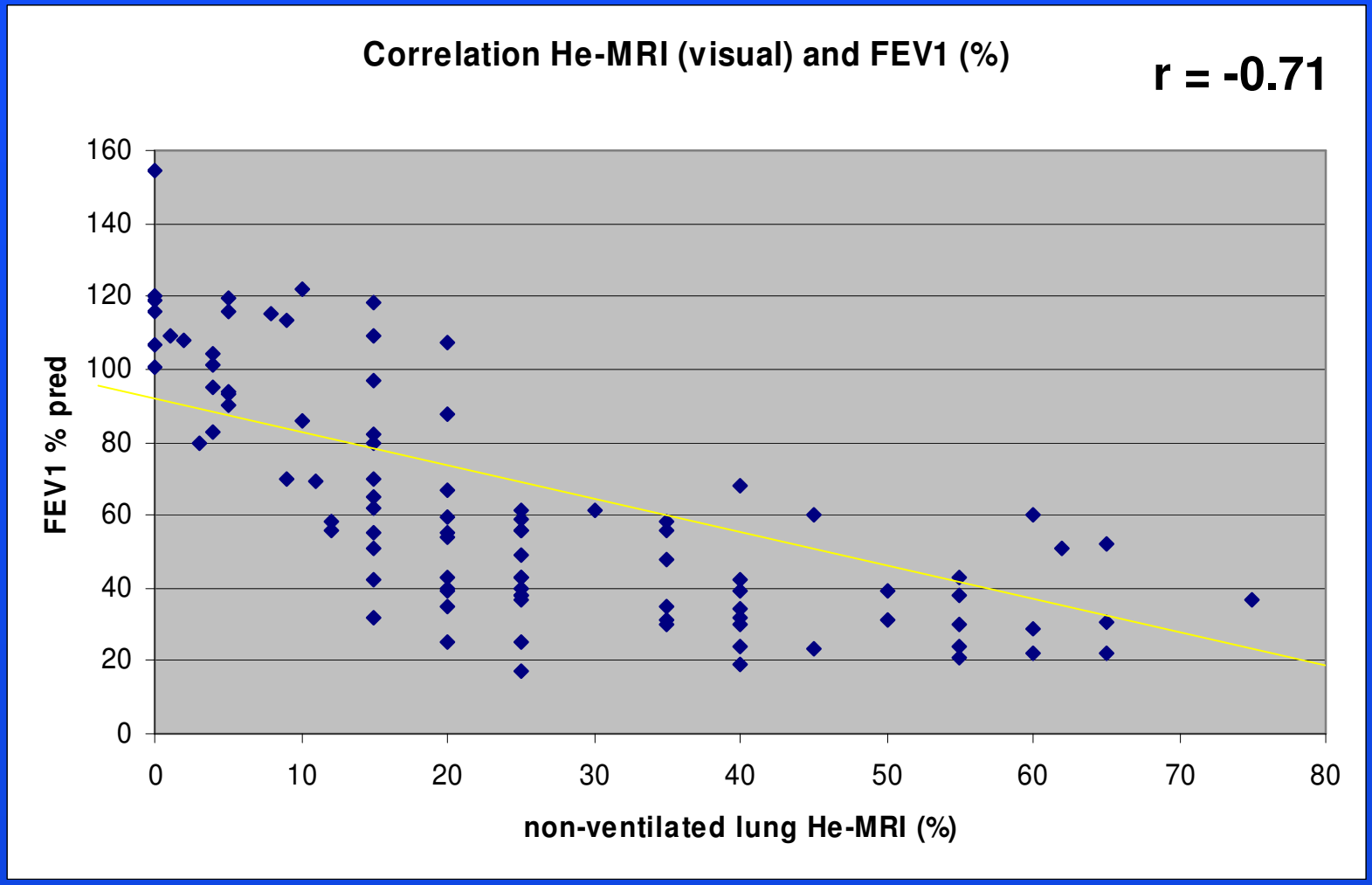




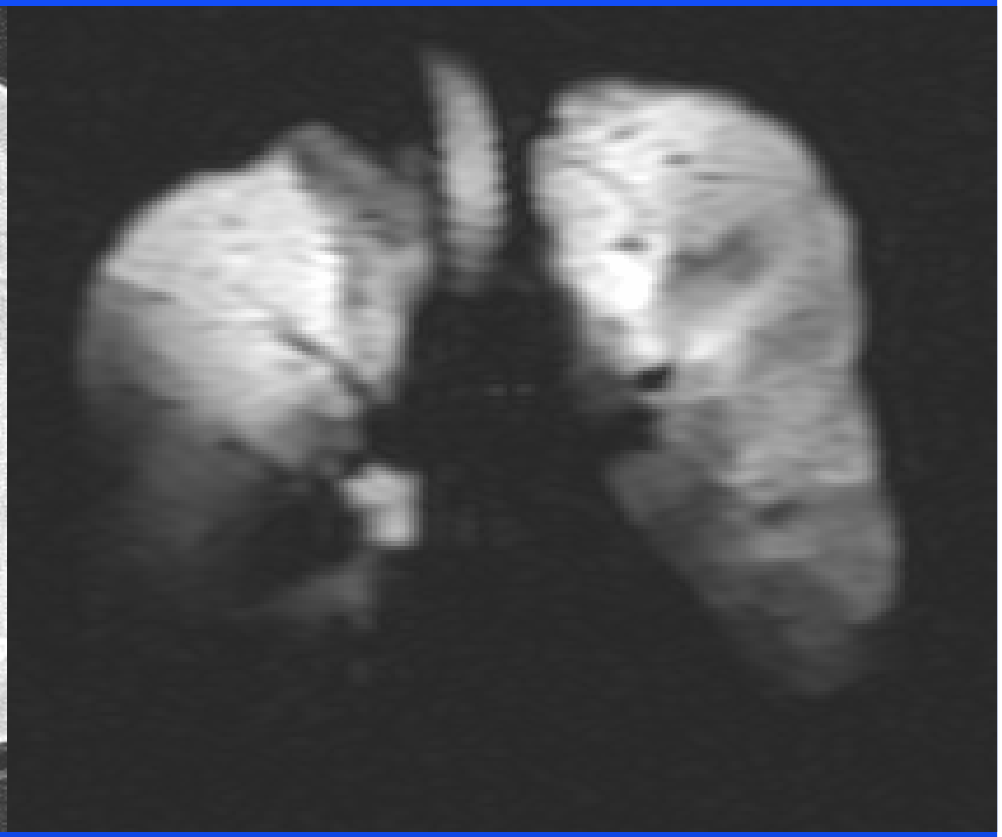
Score 3 moderate

Score 4 severe

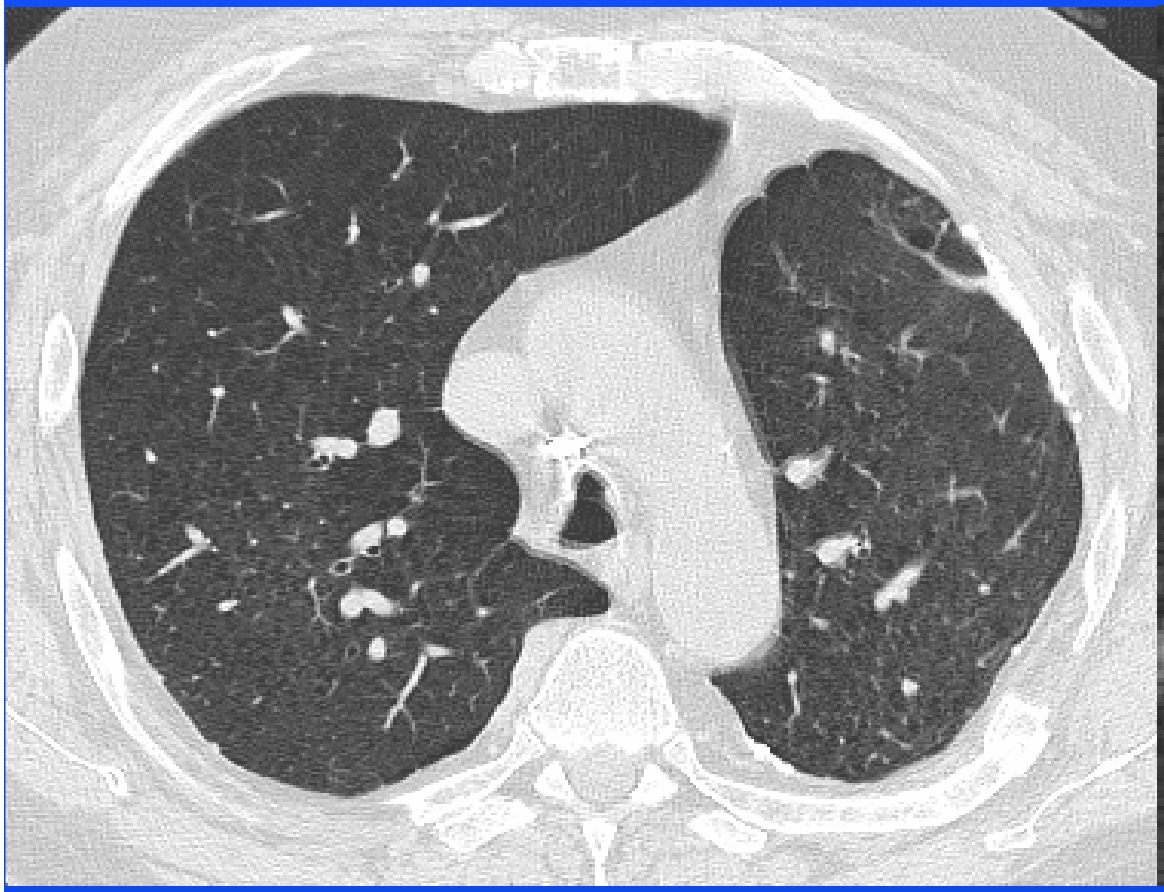
Correlations: ^{3}He-MRI / PFT

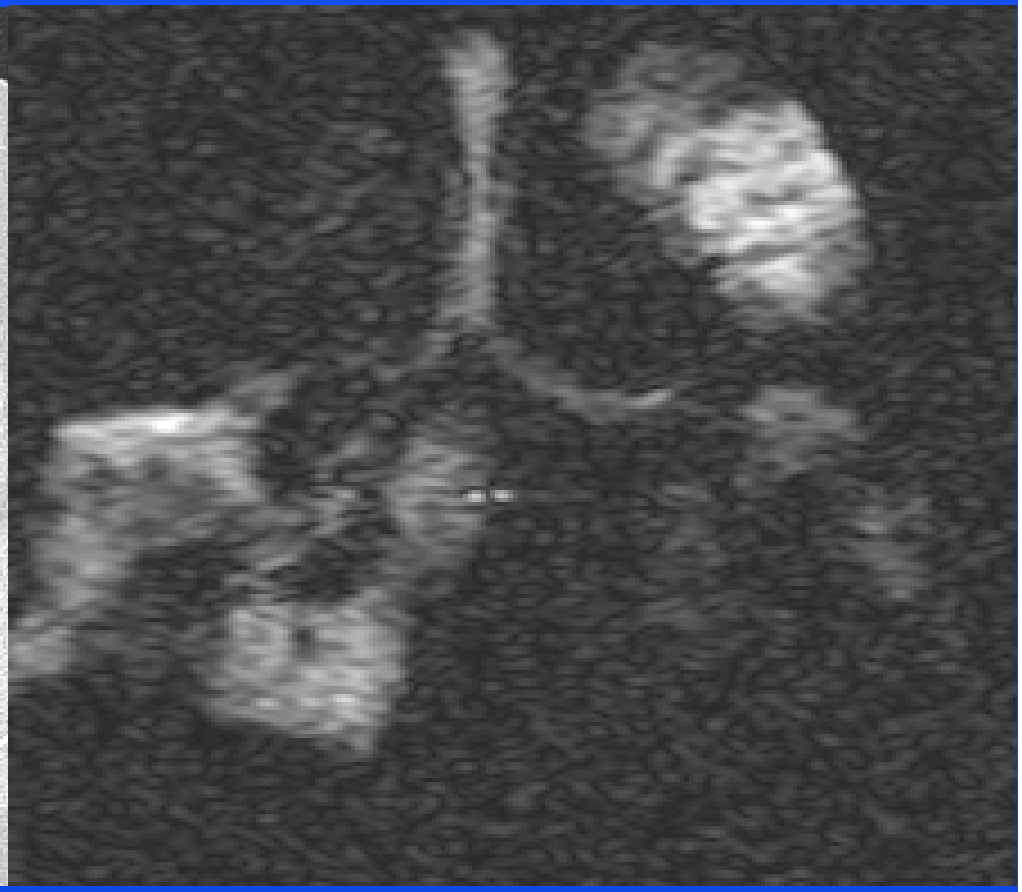


Side-by-Side: CT > ^{3}He-MRI

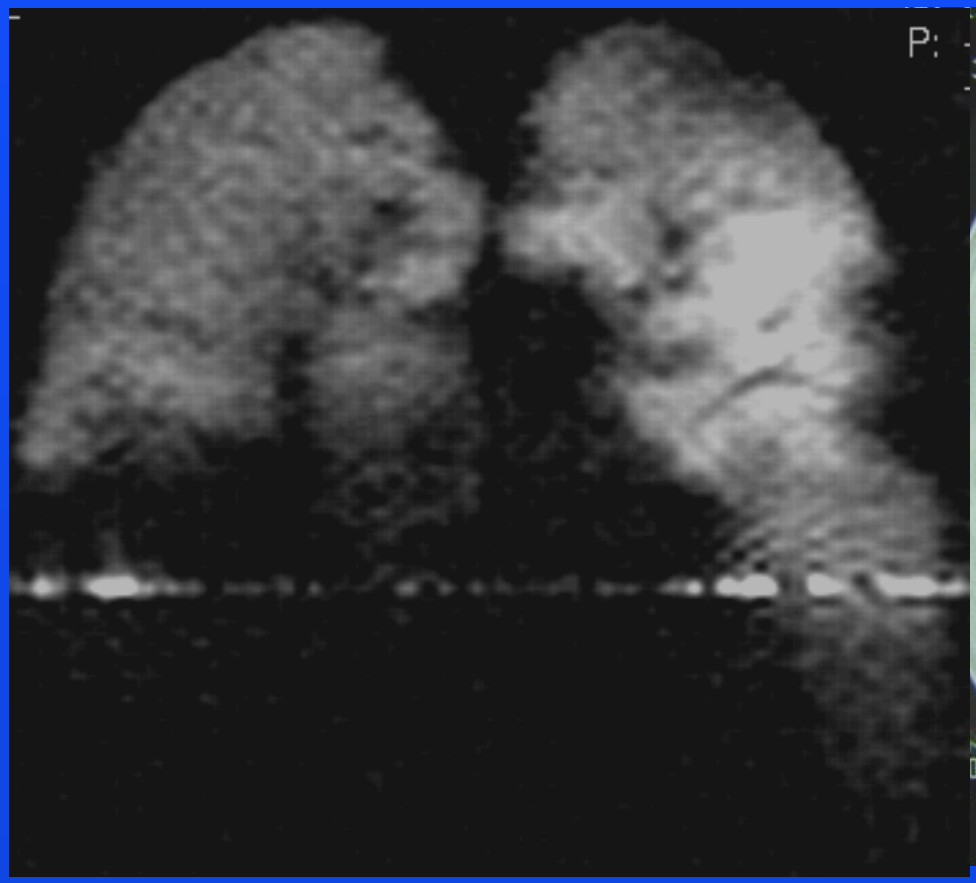


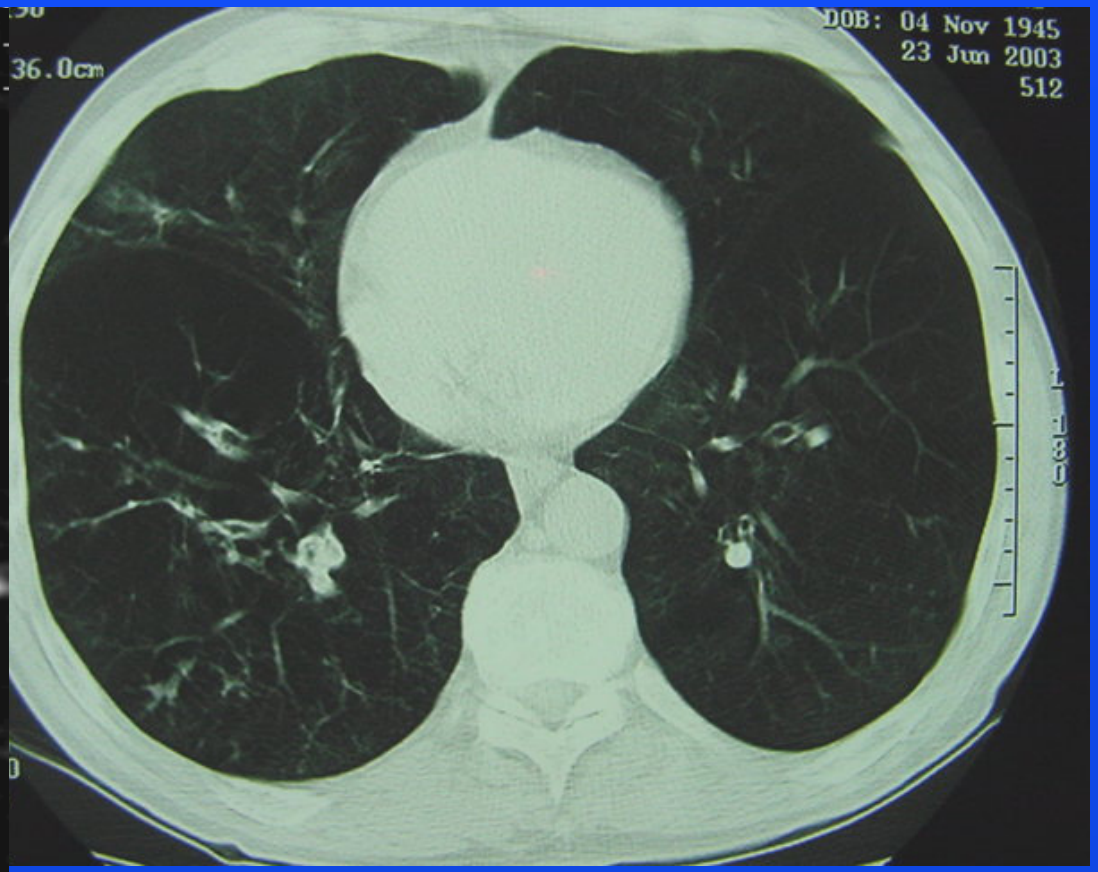
Side-by-Side: ^{3}He-MRI > CT



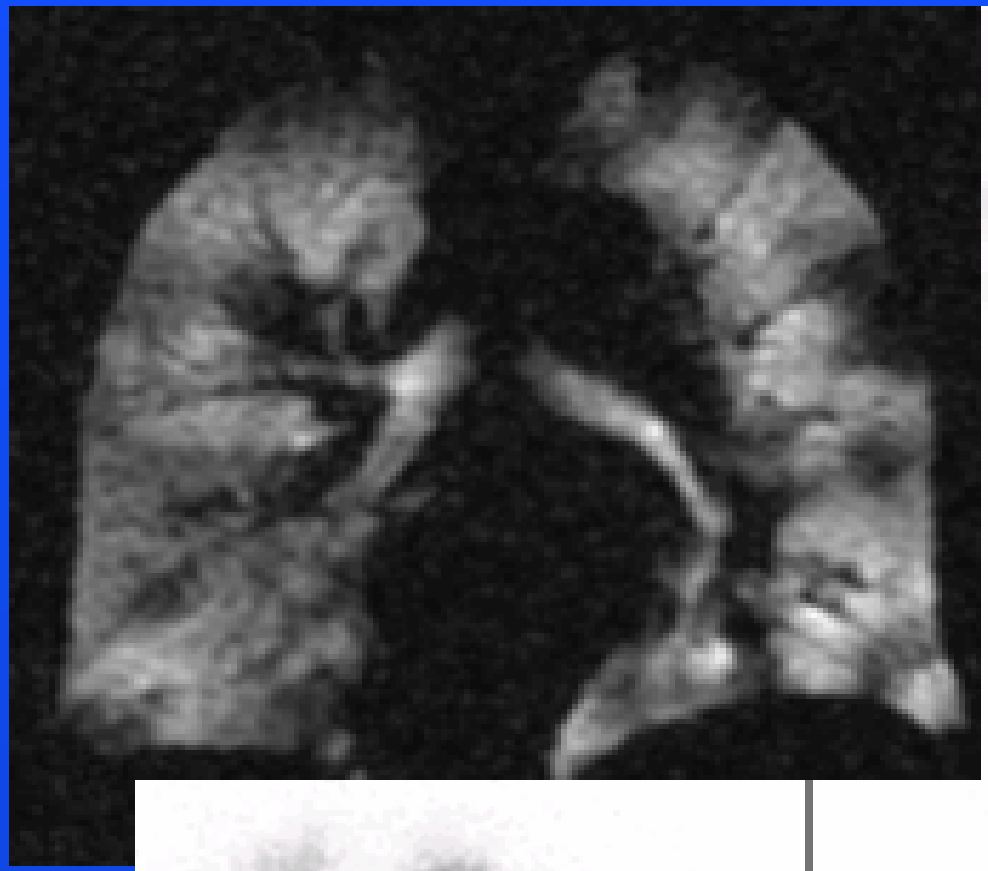


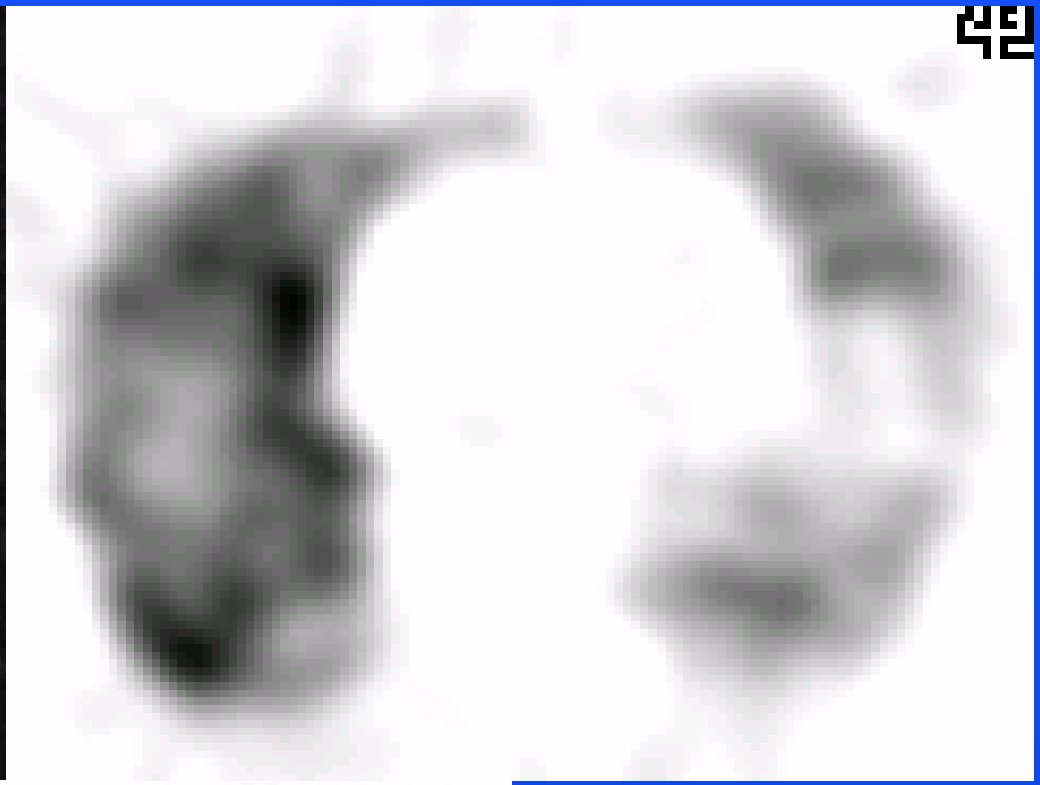
^{3}He-MRI vs. HRCT: Alpha-1-antitrypsin deficiency

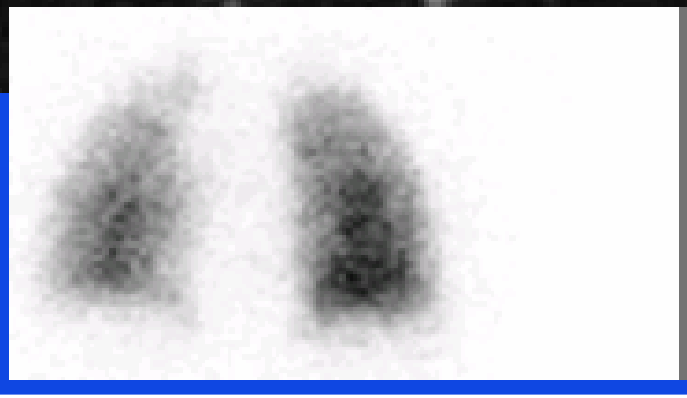


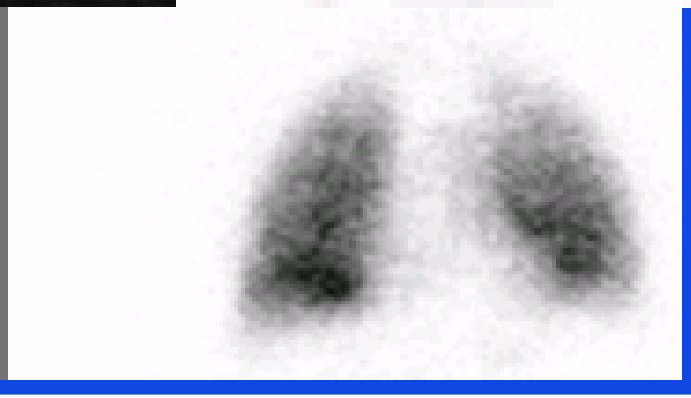


^{3}He-MR vs. Scintigraphy



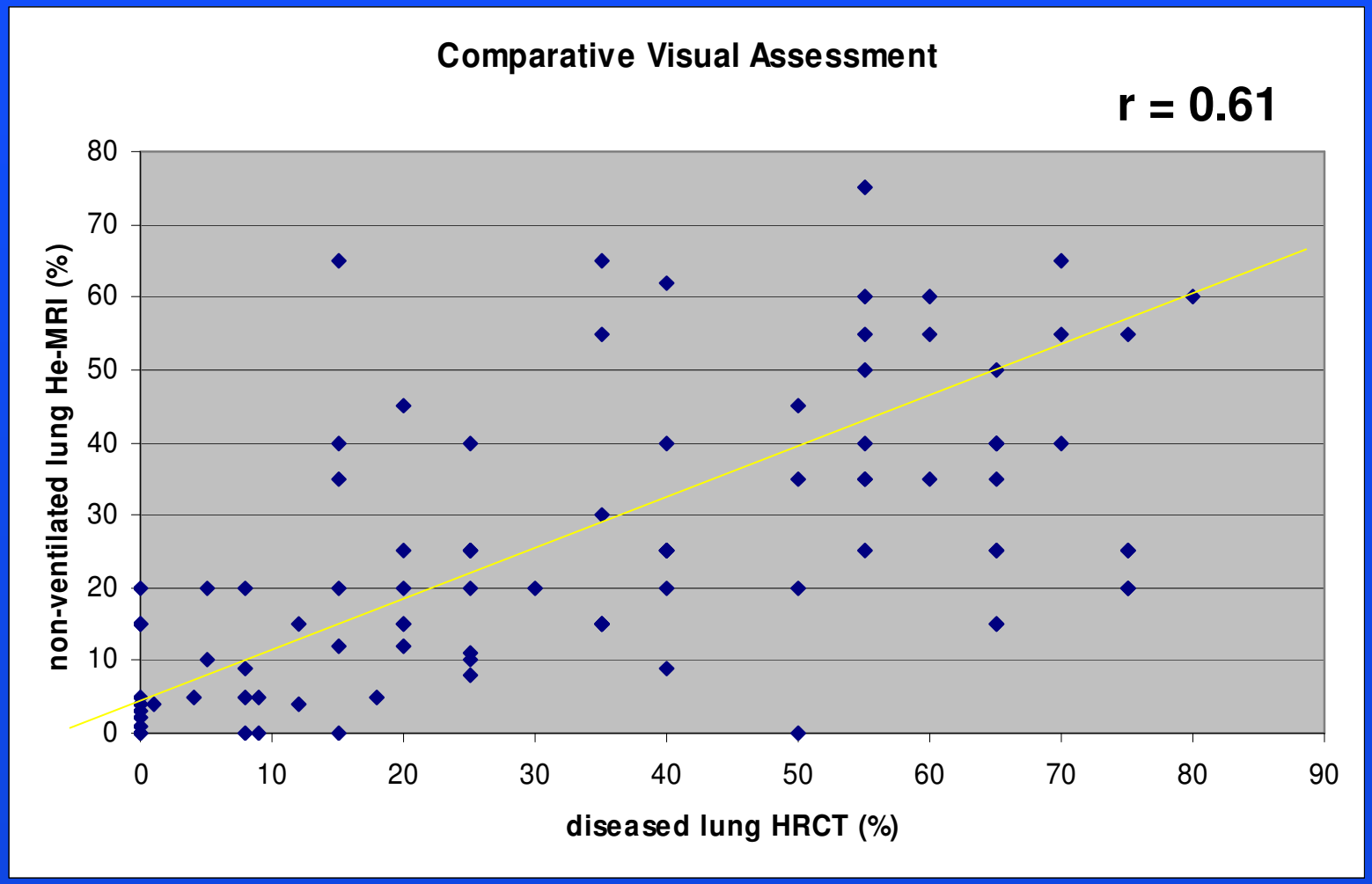




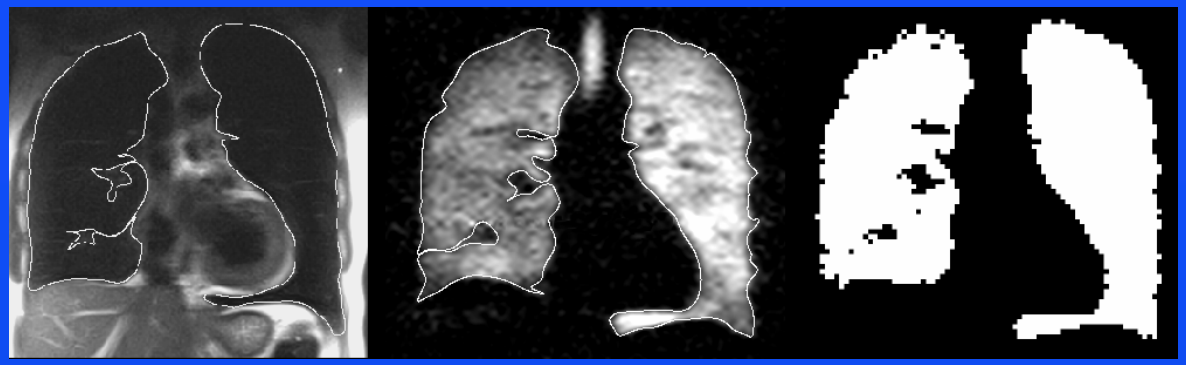


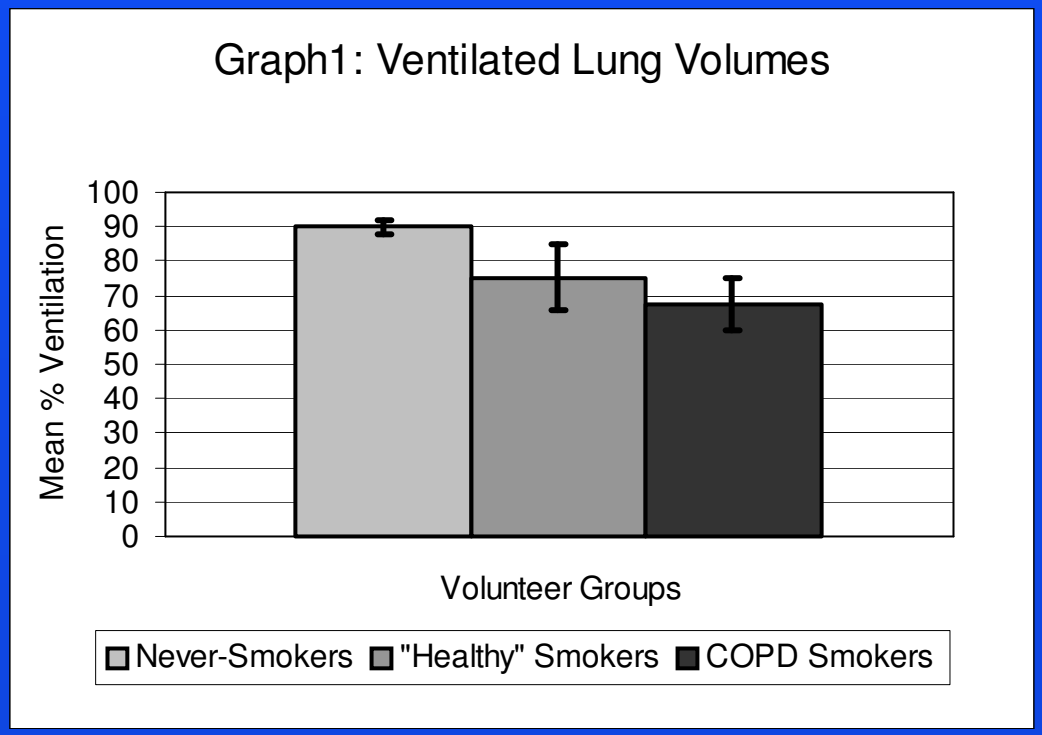
Amersham Health
HPG201

Correlations: CT / ^{3}He-MRI



Ventilated lung volume: quantified





Automatic segmentation feasible for proton and Helium MRI

Using mask image, subtraction leads to "actual ventilated lung volume" within the total lung volume

Excellent correlation with PFTs demonstrated, but REGIONAL information possible

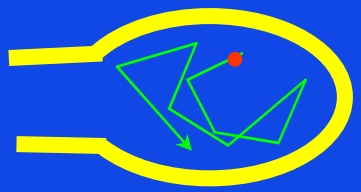
Woodhouse et al. J MRI 2005

Ventilation distribution

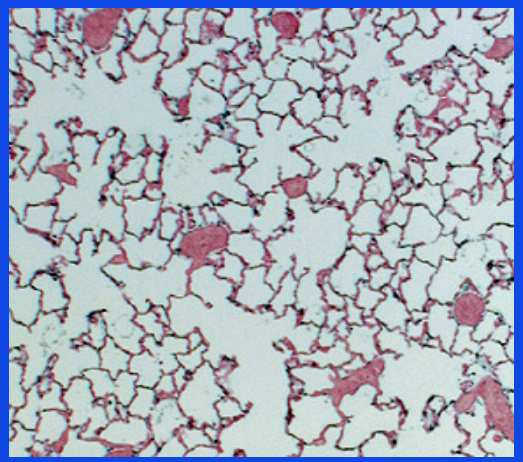
- A good correlation between HRCT and spin density HP 3-He MRI was found. However, MRI tended to underestimate disease compared to HRCT (classification problem?)
- Both correlated with PFT, but in different ways!
- The tests are DIFFERENT in what they demonstrate, but complementary in information yielded (aerated lung vs ventilated lung)

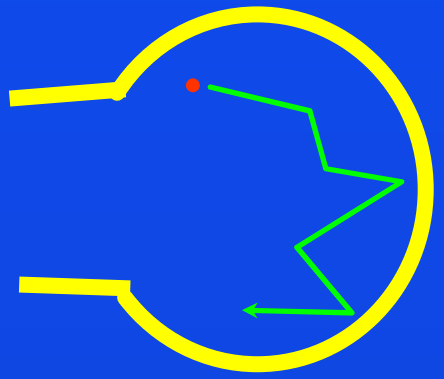
Brownian Motion / ADC

* ^{3}He: high diffusion coefficient (ADC = 1.85 cm^2/sec)
* Diffusion effects influence ^{3}He-images
* Restricted diffusion $\rightarrow$ ADC
* ADC can only be assessed in ventilated areas

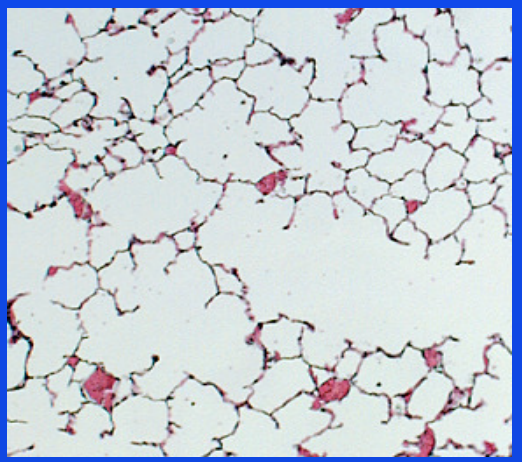


"alveoli"

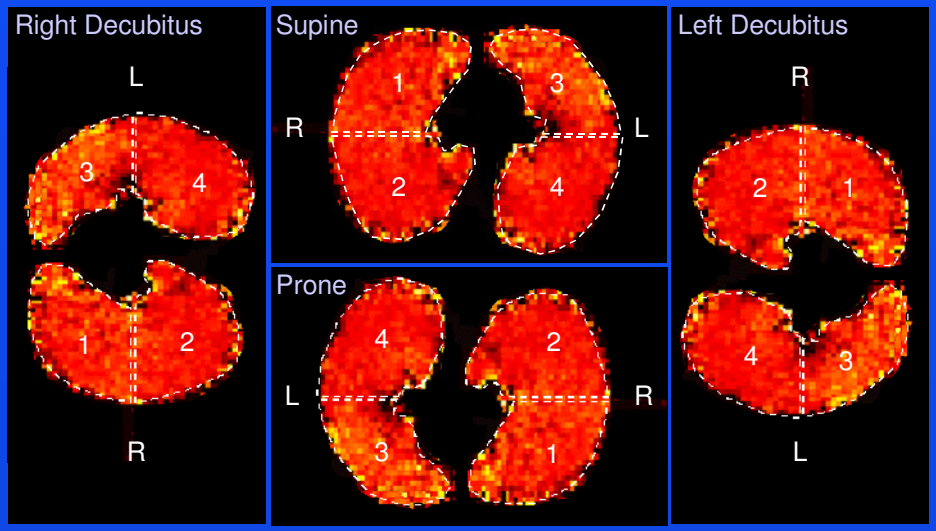




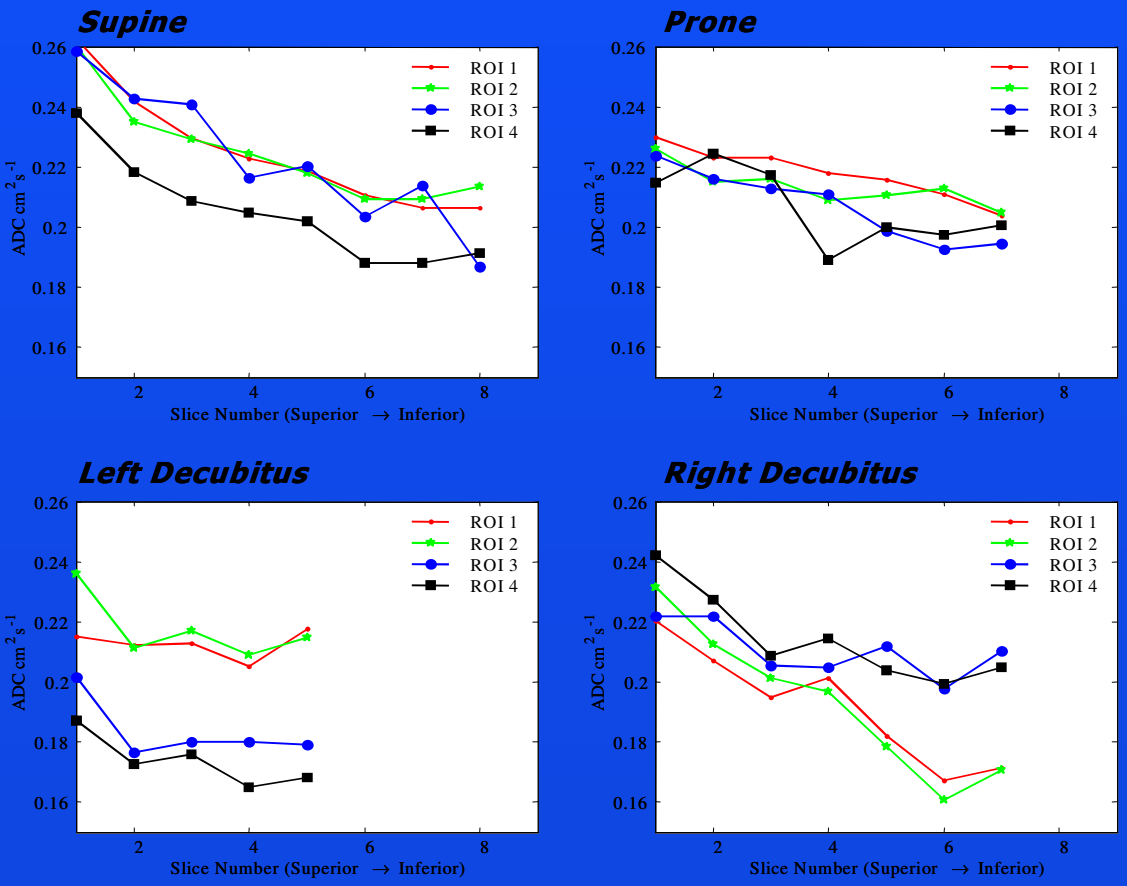
"emphysema"

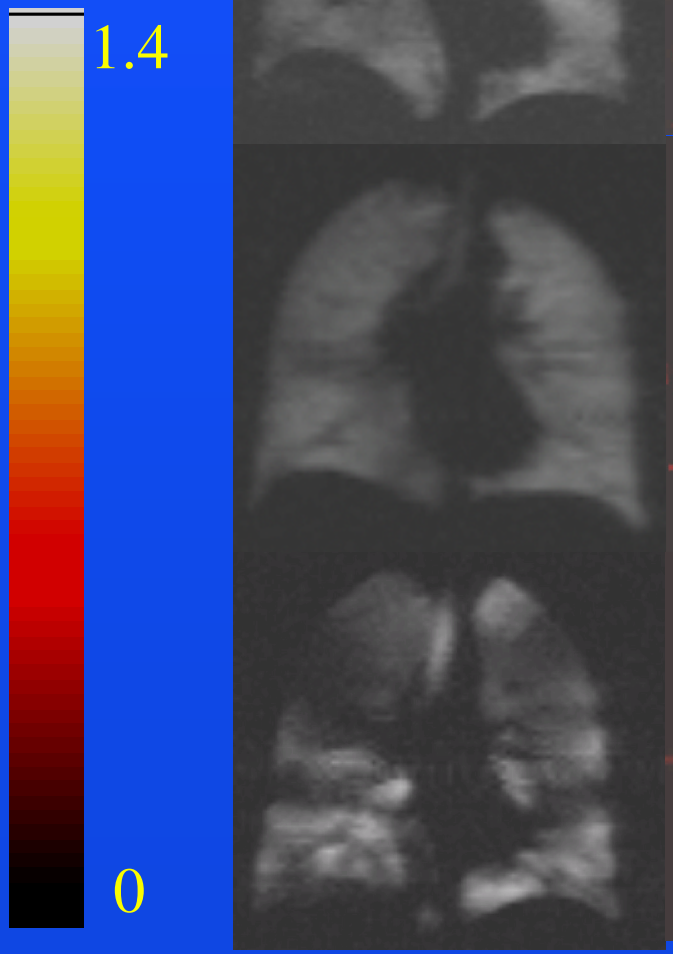


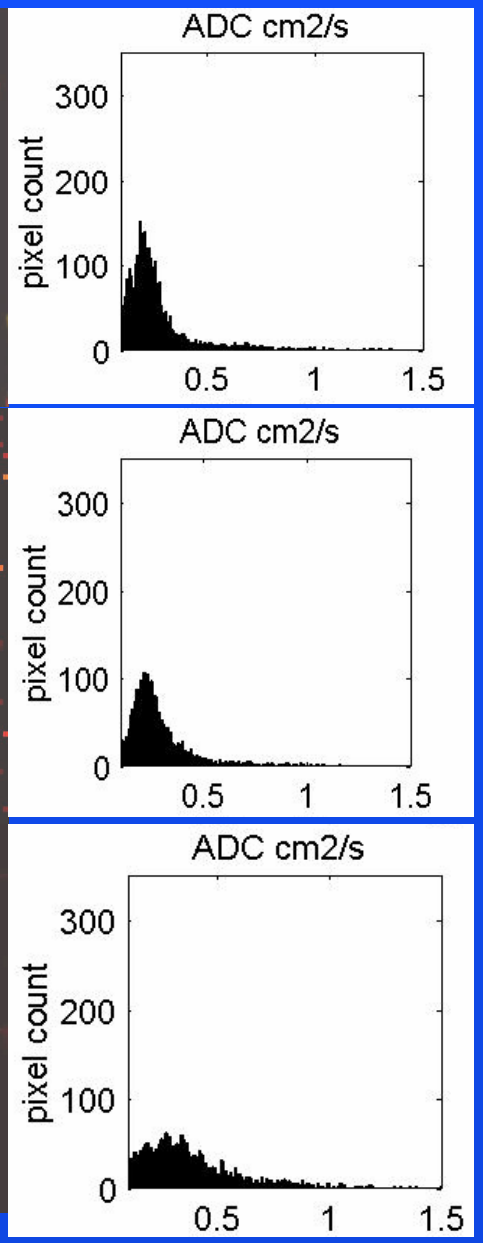
Position influence on lung microstructure



Fichele et al, J MRI 2004





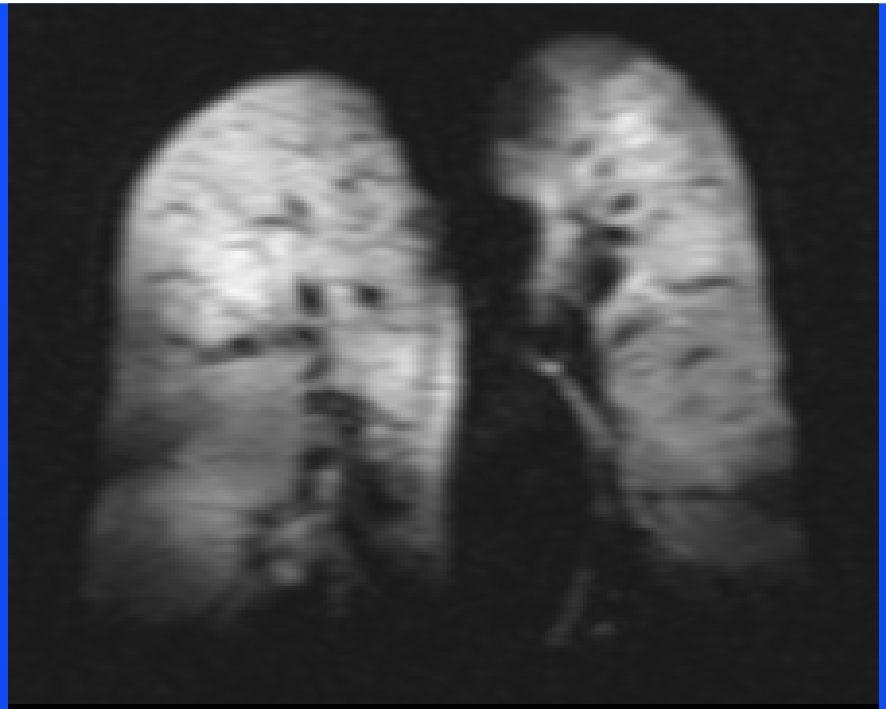


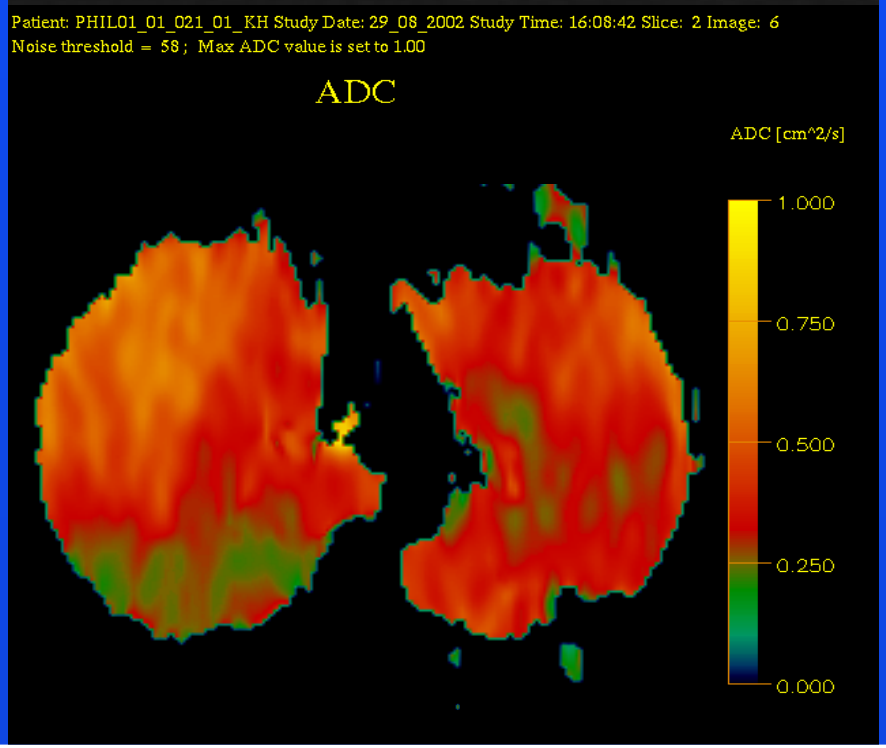
NORMAL

SMOKER

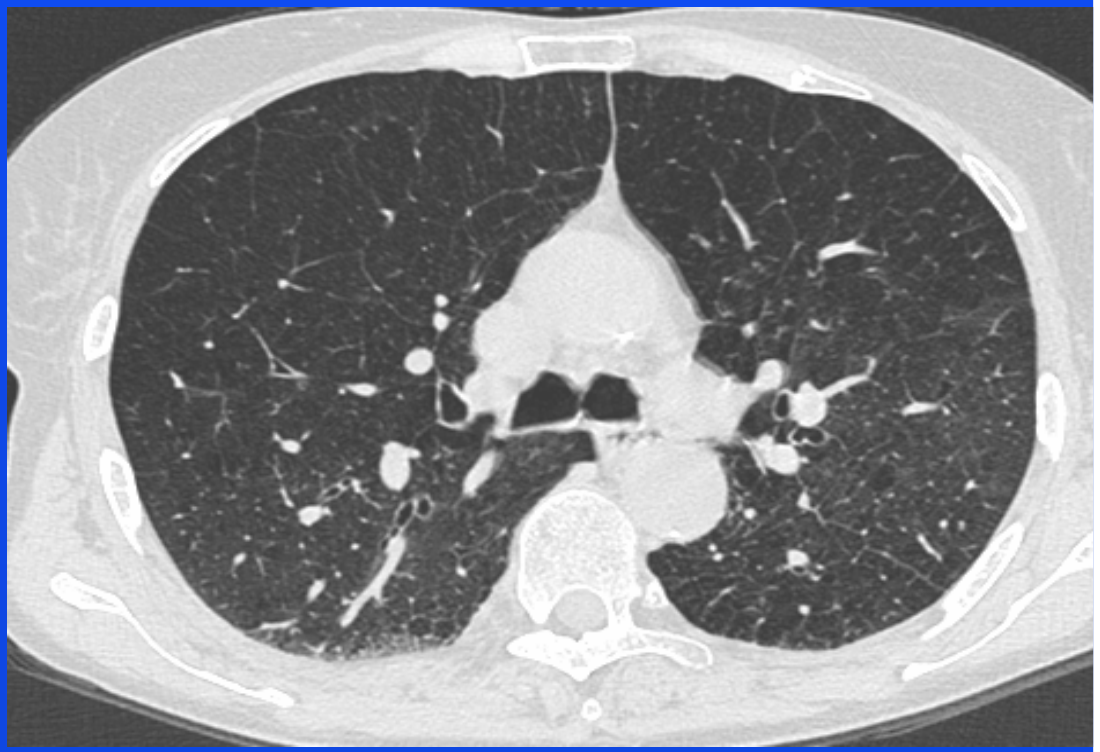
COPD

Swift et al. Eur J Radiol 2005

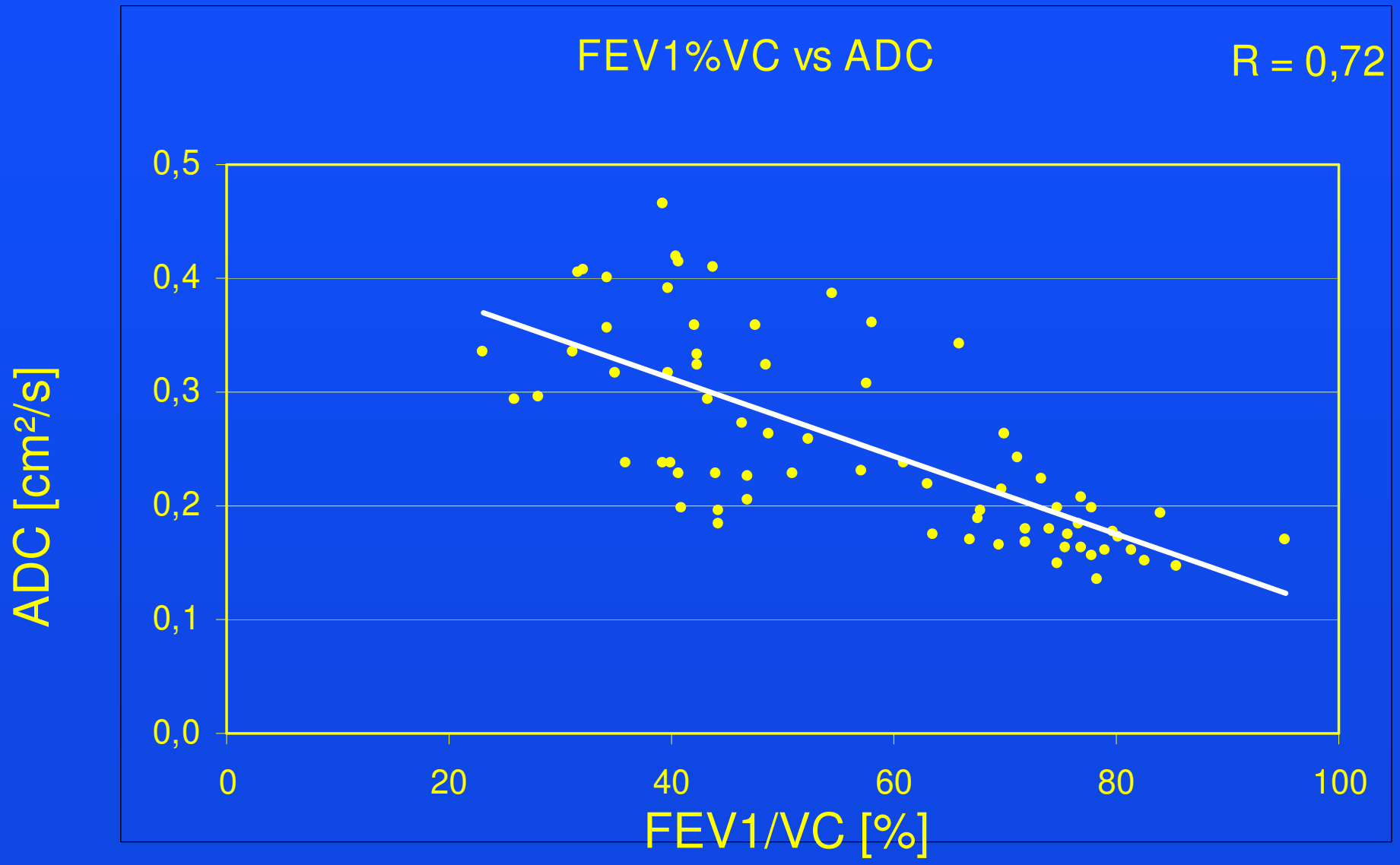




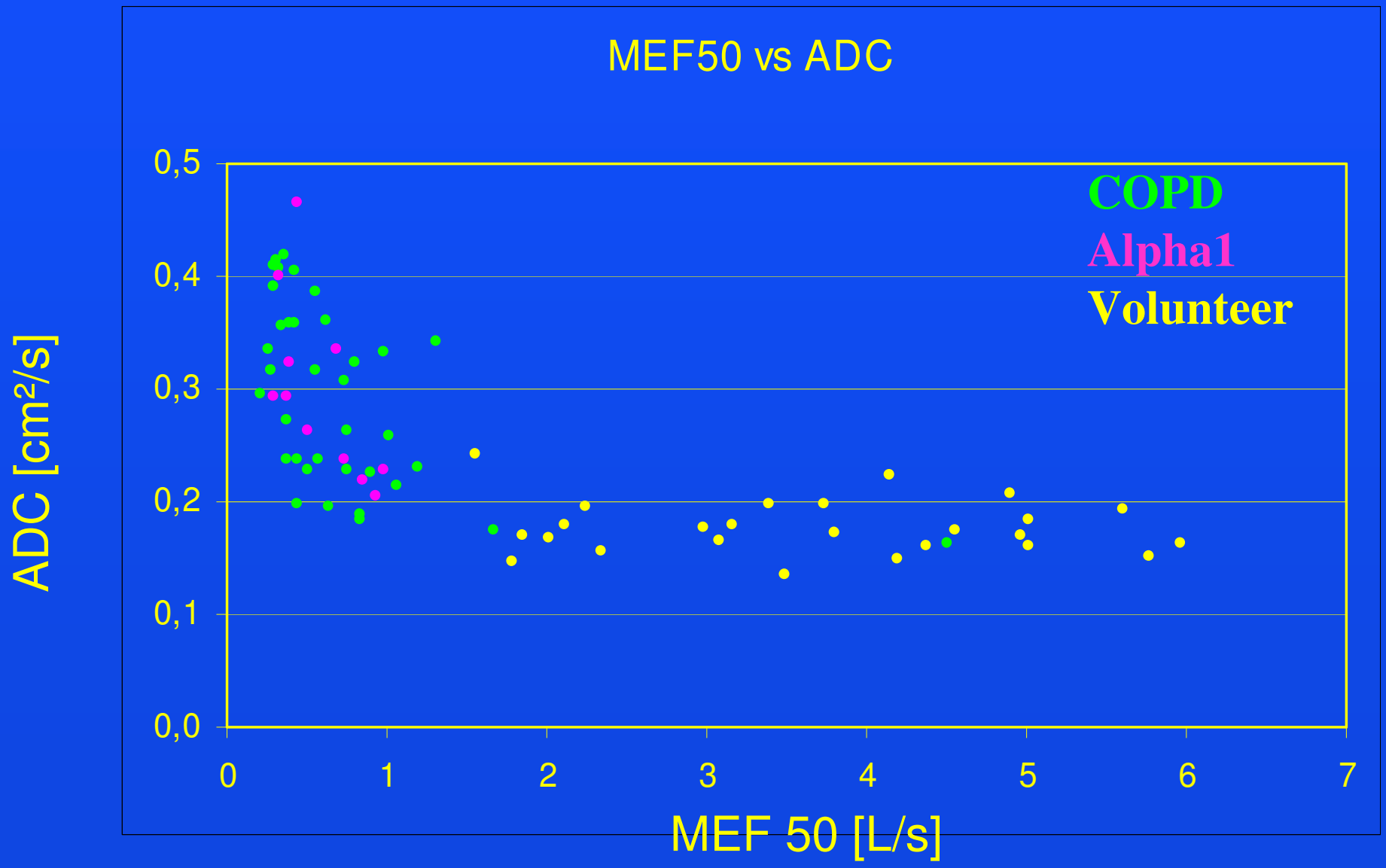
α1-antitrypsin deficiency



Results


FEV1%VC vs ADC
R = 0,72
ADC [cm²/s]
0,5
0,4
0,3
0,2
0,1
0,0
0
20
40
60
80
100
FEV1/VC [%]

Results

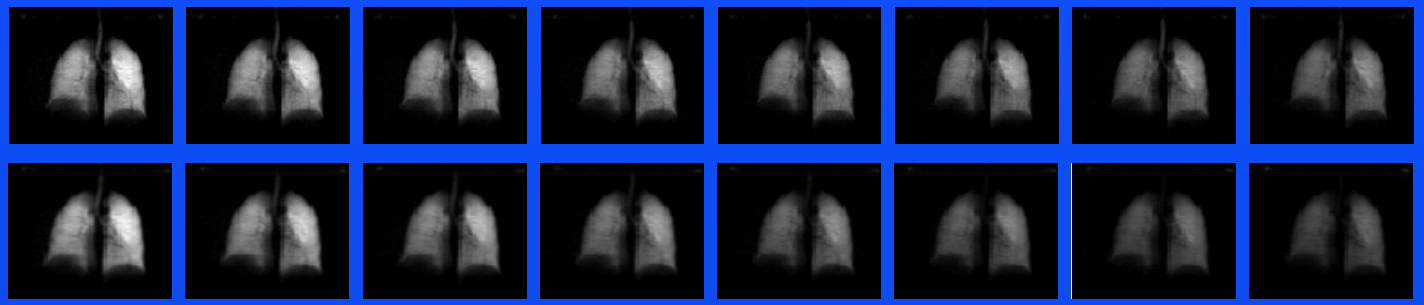

MEF50 vs ADC
COPD
Alpha1
Volunteer
ADC [cm²/s]
0,5
0,4
0,3
0,2
0,1
0,0
0
1
2
3
4
5
6
7
MEF 50 [L/s]

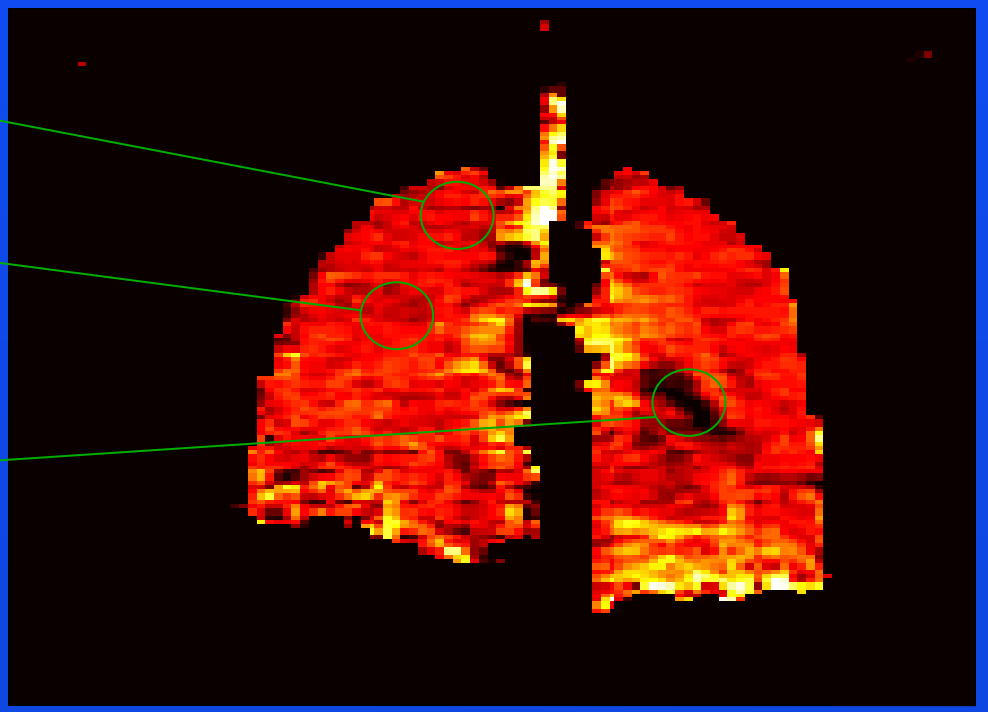
Regional partial oxygen tension

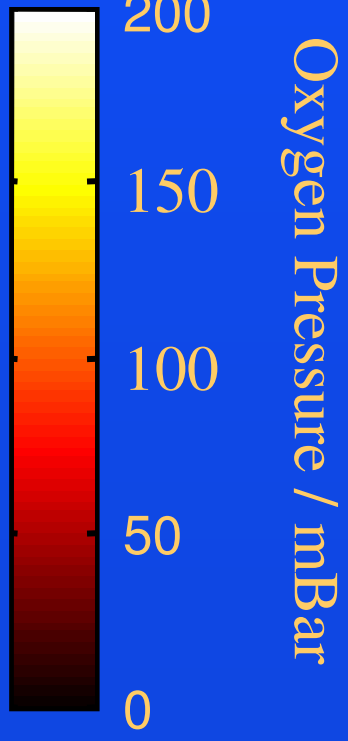
* Ability to assess oxygen uptake
* Ability to address regional ventilation-perfusion coefficient (V/Q)
* Future role? (lung reduction surgery, CTEPH, borderline resectability in lung cancer, therapy monitoring lung diseases)

In-vivo imaging:pO_2

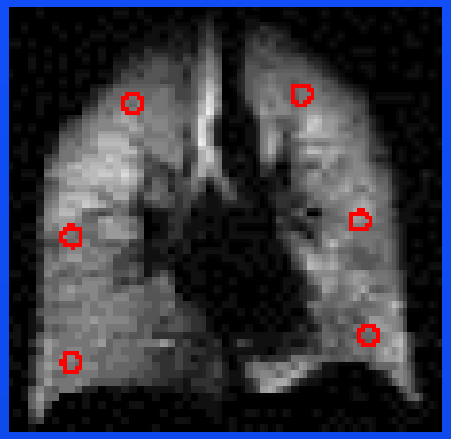
Calculate pO_2 from T1 by acquiring series of whole body projection images with different inter scan delays



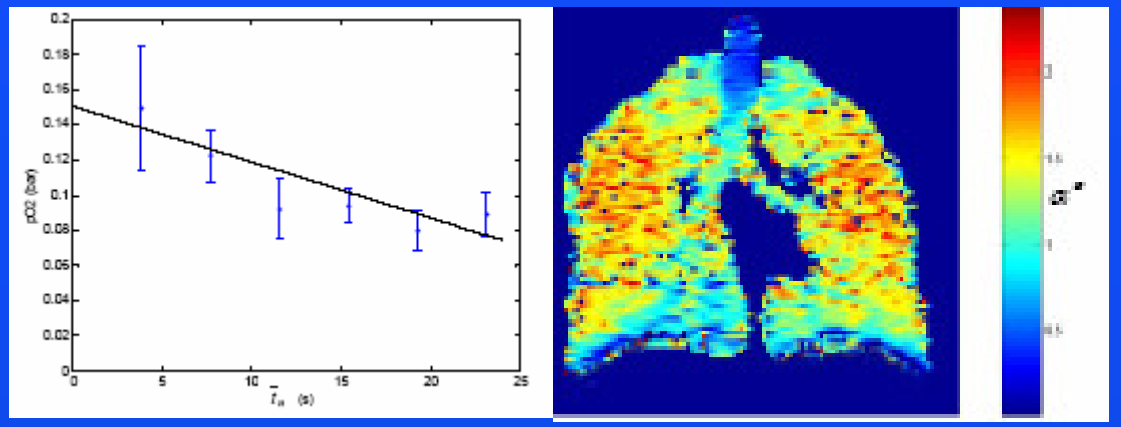


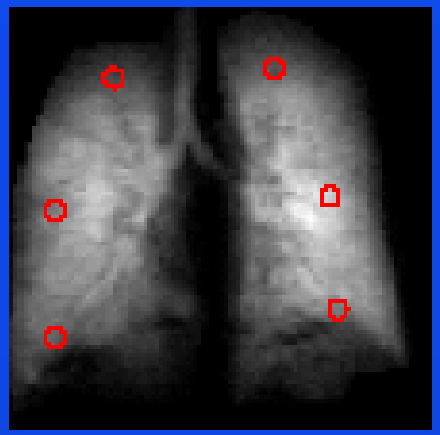


3D oxygen tension map now feasible



2D





3D

Slope of the curve is the signal decay as a function of partial oxygen tension. This represents oxygen uptake from ventilated lung into perfused state

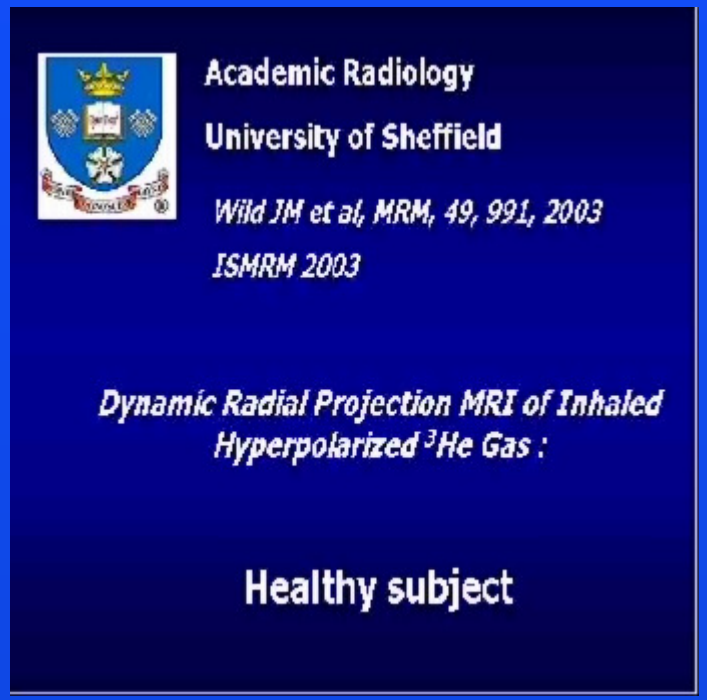
Wild et al. MRM 2005

Dynamic ventilation imaging

* To visualise single breath gas in (and out) flow
* Initially FLASH sequences used at approx 120 ms per frame
* Subsequently spiral sequence developed (Salerno)
* New radial sequence developed in Sheffield (4 ms/frame, sliding window reconstruction)

Wild et al. MRM 2003

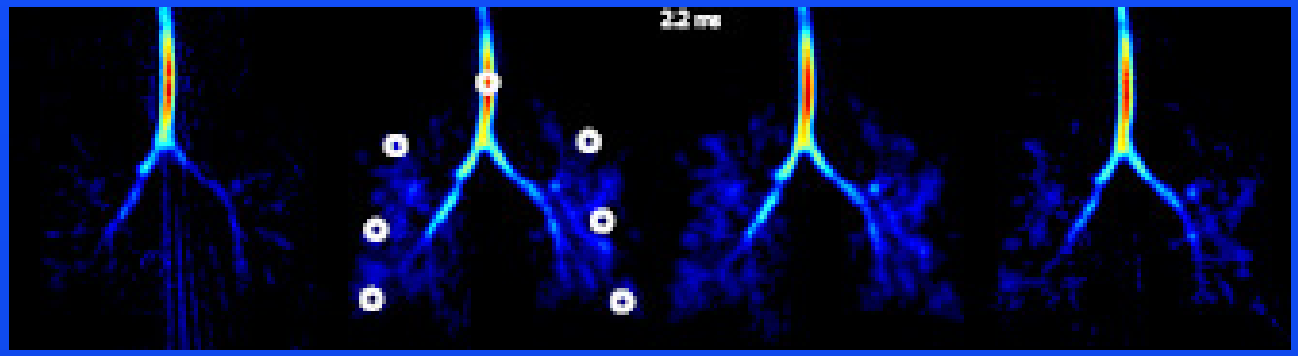
Dynamic information

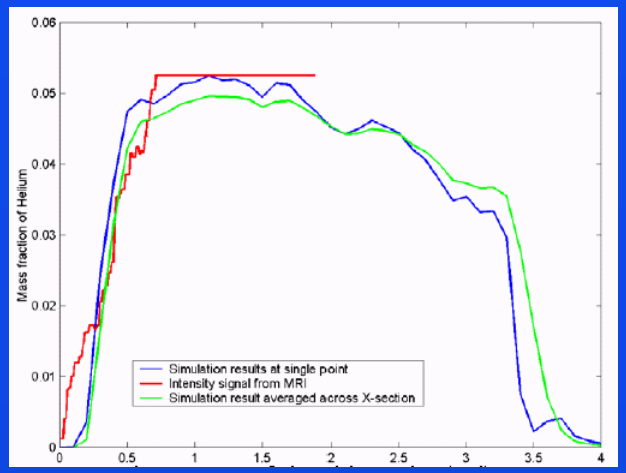


Dynamic ventilation imaging

* Pretty movies, but what does it mean?
* We are able to measure 3He gas inflow into the lungs, so what ?
* Well, what if we can quantify this inflow or even outflow if we change our imaging protocol?
* This would lead to regional spirometry (or some people have called it “fractal ventilation”)

Dynamic assessment of airflow – regional spirometry





The upslope of the signal intensity curve is a direct measure of airflow into the distal airways (ROI), using the trachea as input function

Koumellis et al. J MRI 2005

HP gas MR imaging: future uses

* Imaging of emphysema: can it assist in the pre-operative planning of lung reduction surgery?
* Can it detect early emphysema and assess early intervention changes?
* Can it probe collateral ventilation?

New publications worth mentioning

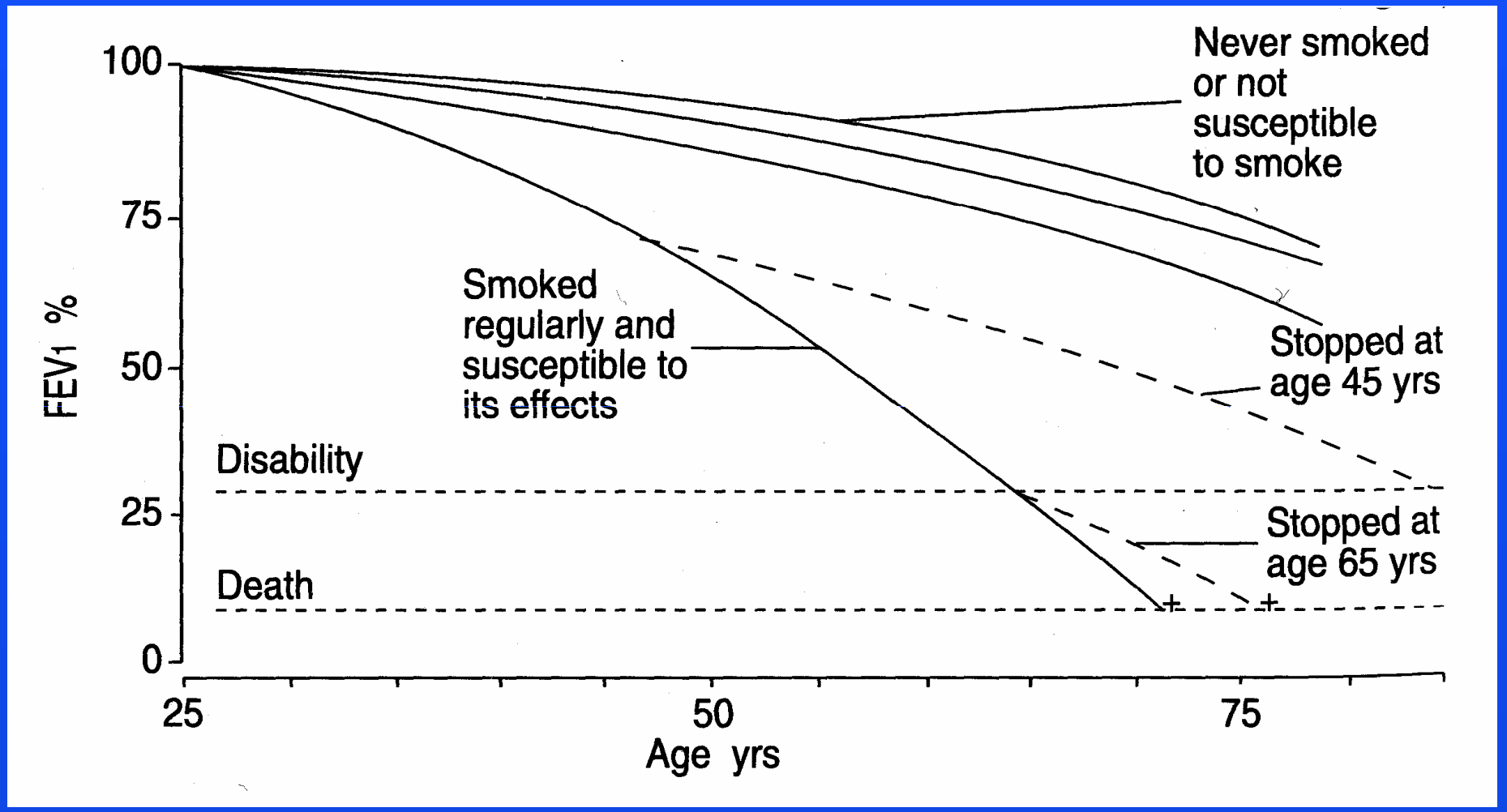
* ADC is age dependent

  Fain et al. Acad Radiol 2005

* Long time-range ADC may be a potent way to assess the issue of collateral ventilation

  Conradi et al. Acad Radiol 2005, Conradi et al. J Appl Physiol 2006 (in press), Woods et al. MRM 2004, Woods et al. J Appl Physiol 2005, Wang et al. MRM 2006

Who gets COPD?



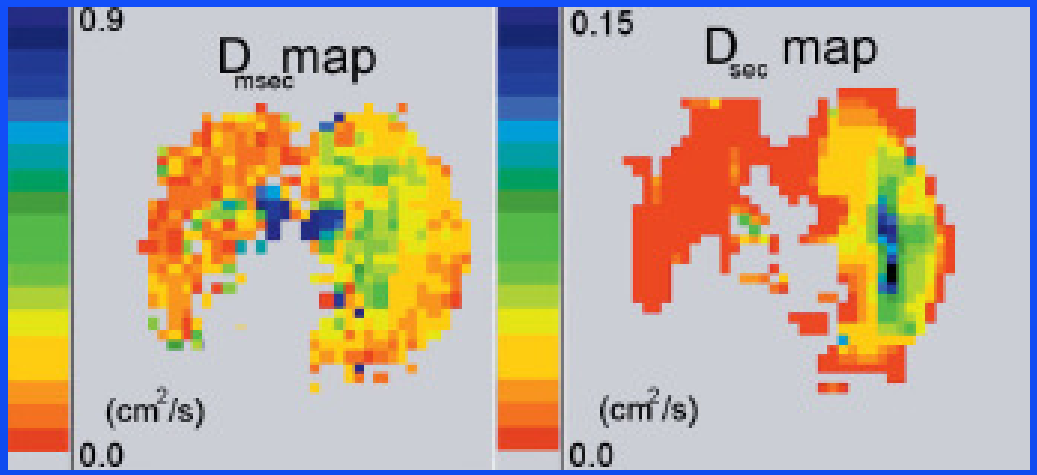
Genetic susceptibility has a role to play !

1 in 3 subjects are thought susceptible

Collateral ventilation

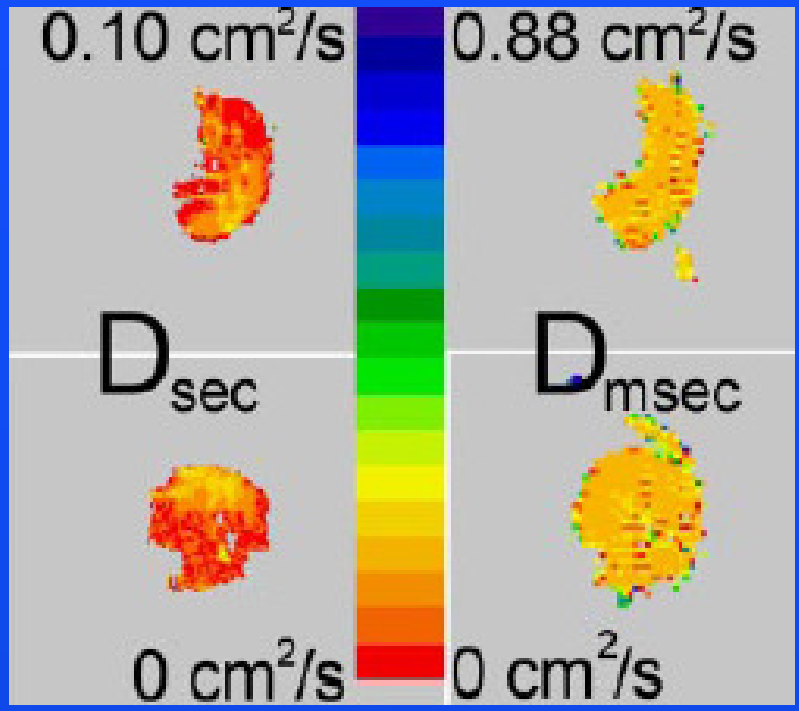
* Very important physiological phenomenon
* Also clinically relevant, for instance when considering interventional therapy for emphysema (valves)
* Long time-range diffusion measurements provide information on air way connectivity (and thus collateral ventilation), as it measure diffusion over a much greater trajectory
* Long time-range diffusion also seems more sensitive to airspace size increase

Collateral ventilation



Woods et al, MRM 2004

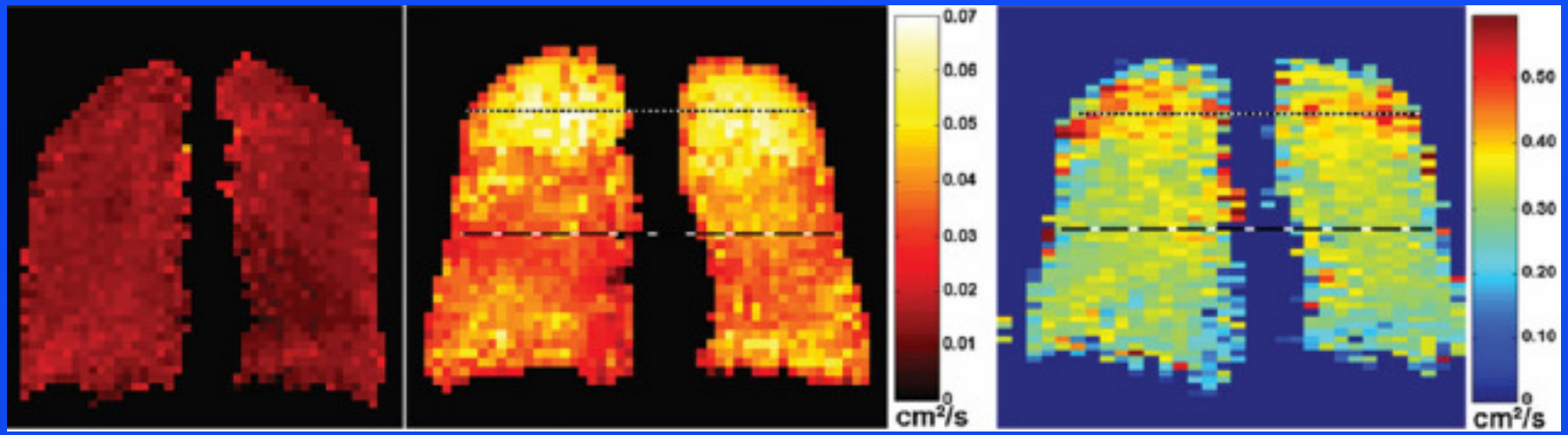
Dog emphysema model with short vs long time-range ADC; (emphysematous lung on right)

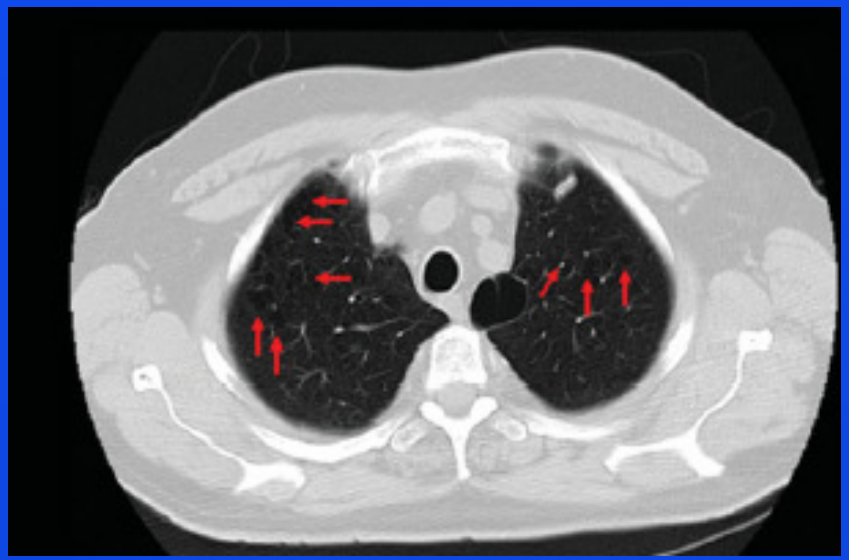


Woods et al, J Appl Physiol 2005

Two human normal donor lungs, demonstrating greatly different ADC values depending on time-range

Long time-range ADC – earlier detection of emphysema





Wang et al, MRM 2006

Normal volunteer vs patient with subclinical emphysema demonstrating much greater long-range ADC changes compared to “standard” ADC

Conclusions

* Increase in use of “functional” information from imaging studies
* Both CT and MRI are under development, each with their own advantages/disadvantages
* MRI of the chest will increase over the next few years, not only using HP 3He but also using other new sequences for parenchyma and perfusion.
* Novel methods should focus on QUANTIFICATION above anything else if it is to make an impact in clinical medicine
* 3 He MRI will be a winner, but exact role to be determined

Thank you!

University of Iowa

University of Sheffield