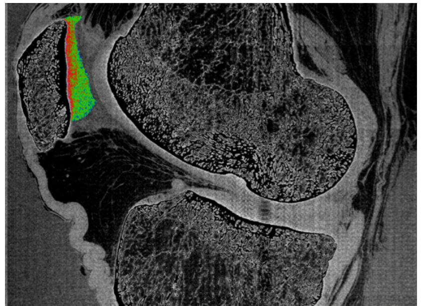
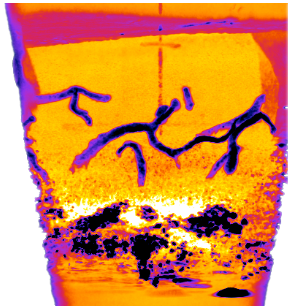
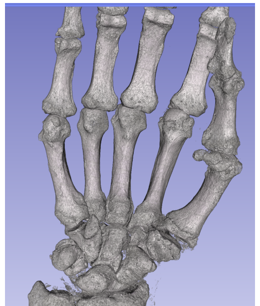
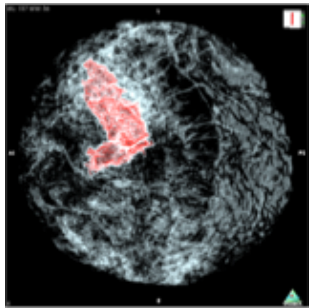
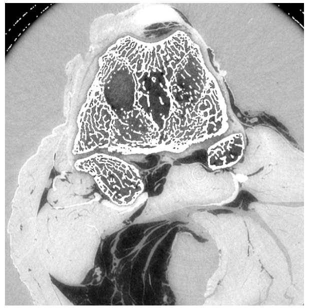
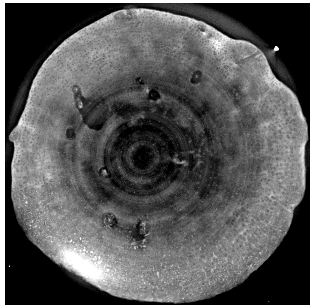
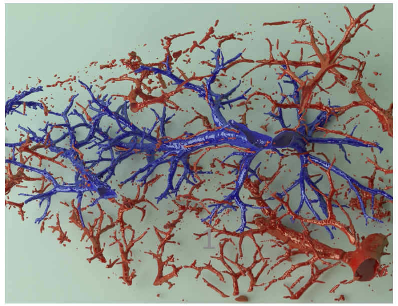
BioMedical quantitative X-Ray Imaging

Emmanuel Brun

Researcher – Inserm – Université Grenoble Alpes

Outline

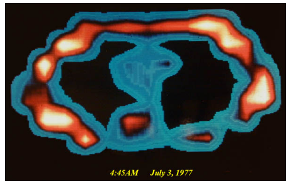
- Introduction
- K-Edge Imaging
- Patient imaging at the European synchrotron
- Medical Phase Contrast Imaging
- High Resolution Phase Contrast Imaging for medical research
- Conclusion

A brief history of time in medical imaging

MRI

Nuclear Medecine

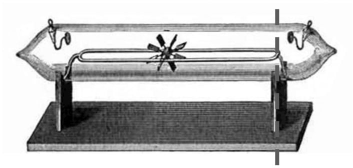
- 1882 – Tesla's discovery of rotating magnetic field
- 1896 – Becquerel discovery of uranium natural radioactivity
- 1901 – Curie(Brachy)Therapy
- 1934 – Joliot-Curies' artificial radioactivity discovery
- 1950 – Spin echo (Hahn)
- 1954 – First scintigraphy
- 1975 – Positron emission tomography
- Lauterbur invents MRI
- 1977 – Damadian shows that tumors has a different NMR signature



X-ray

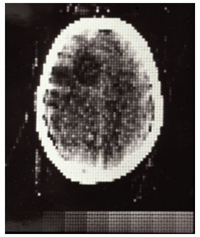
Ultra-sound

- 1869 – Crooks tubes Cathode rays



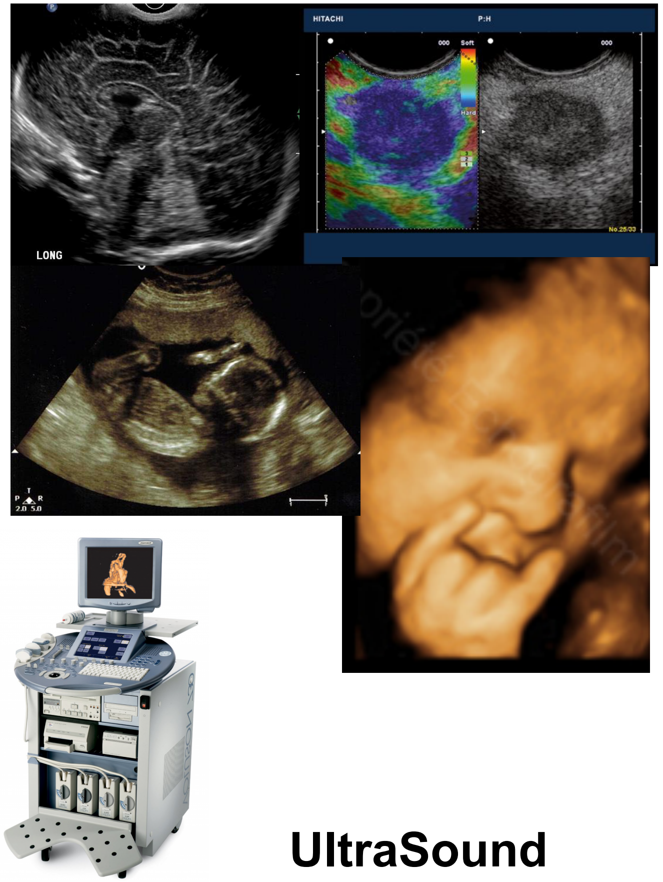
- 1877 – Rayleigh's Theory of sound
- 1895

- 1917 – Johan Radon publishes his Radon Transform
- 1935 – First RADAR
- 1942 – First medical application of ultra sound
- 1947 – 1st Synchrotron project
- 1963 – Cormack first paper
- 1971 – First Clinical Scan (Hounsfield and Ambrose)

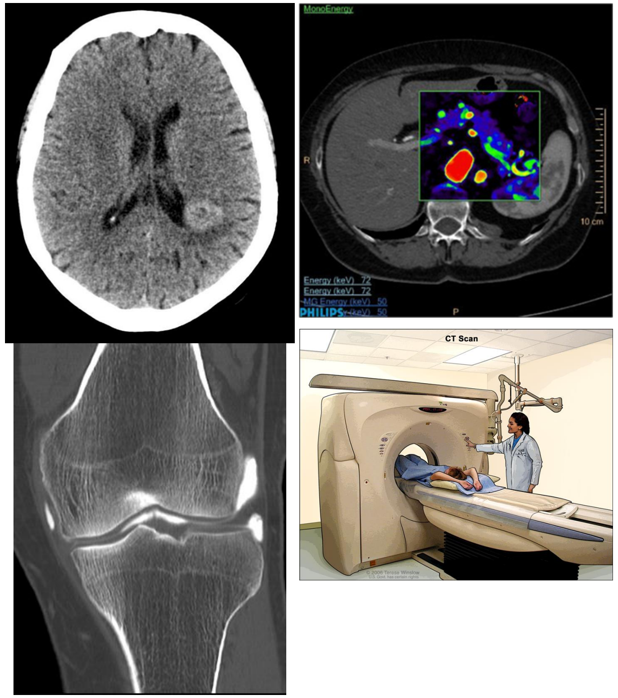


- 1980's – 1st µCT
- 2013 – 1st Human Synchrotron CT

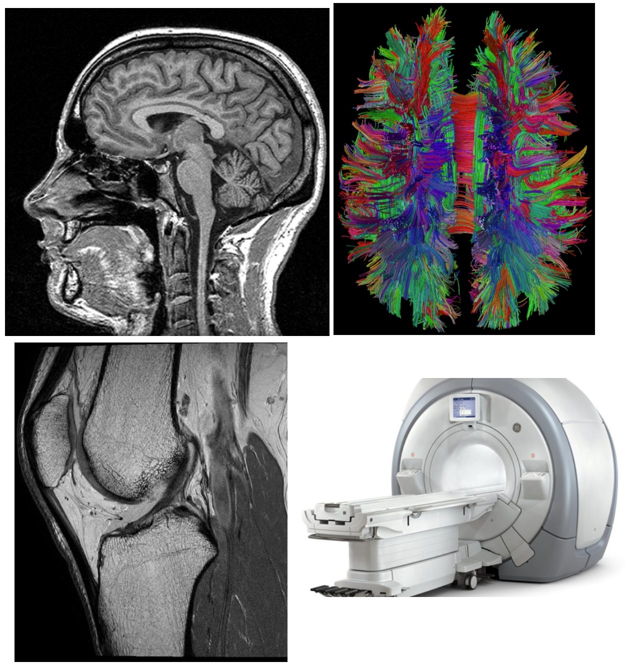
A variety of imaging modalities



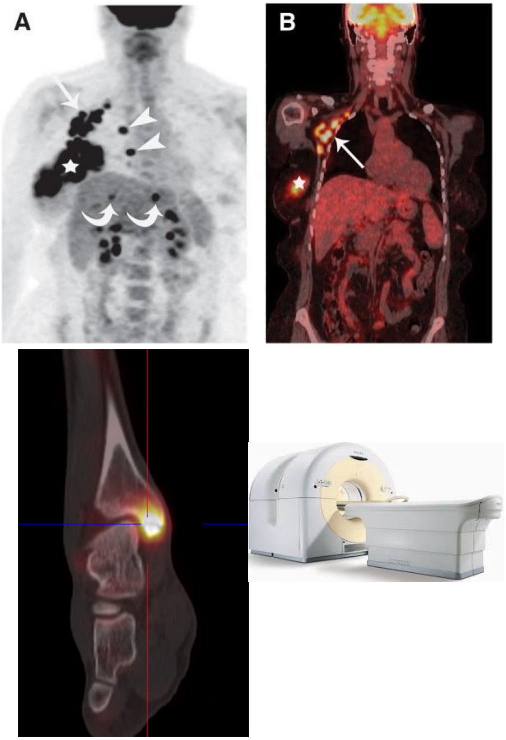
UltraSound



X-ray CT



MRI



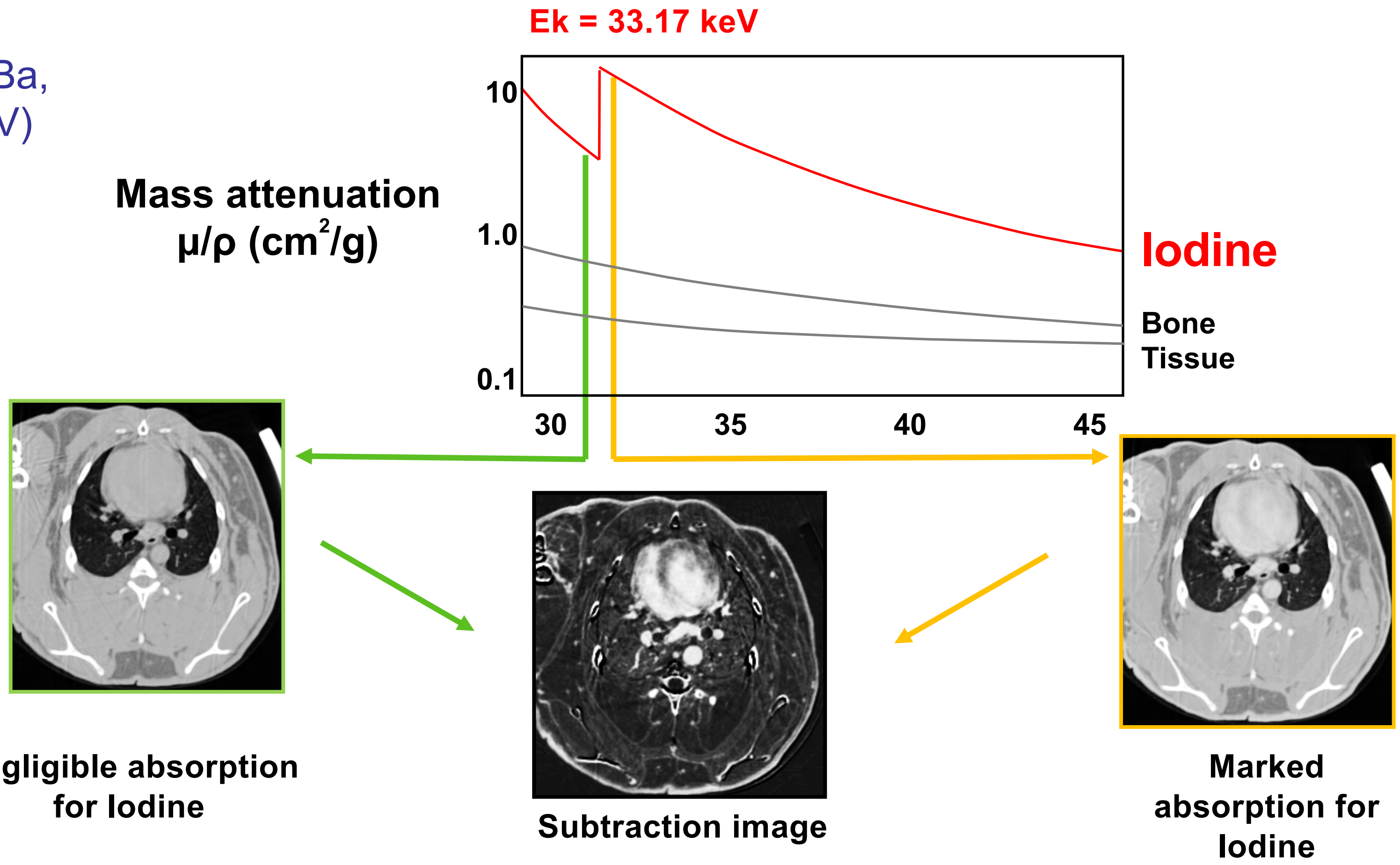
PET CT

Why developing new imaging modalities?

- Spatial resolution
- Contrast sensitivity
- Temporal resolution

K-edge subtraction (KES) imaging (Iodine infusion)

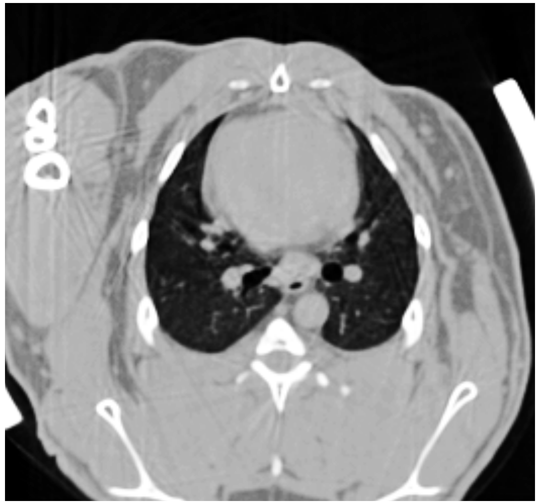
ID17, ESRF:
Ag (80.72 KeV), …, Gd, Ba,
Ho, Yb, …, Au (80.72 KeV)



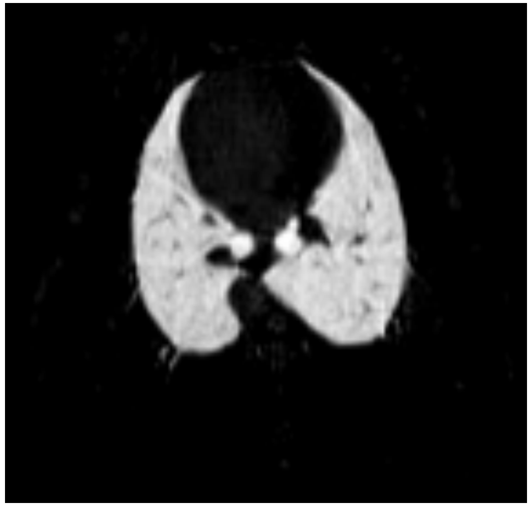
Bayat et al. *Phys Med Biol* 2001

KES imaging *in vivo* rabbit

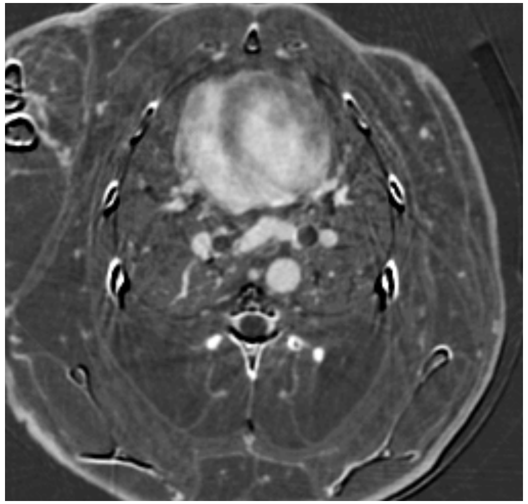
Tissue Density



Xenon



Iodine



Applications of KES imaging

- High brilliance of synchrotron x-rays
  Direct **quantification of contrast elements** within organs

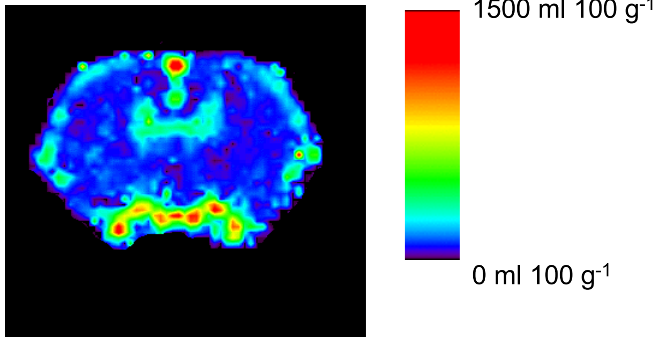
- Access to data on organ function:
  Regional lung ventilation : Xenon
  Perfusion (organ, tissue): Iodine, Gadolinium

- Spatial resolution : current resolution on ESRF-ID17 : 1 µm; *in vivo* ~3 µm

IV Coronary Angiography
Human

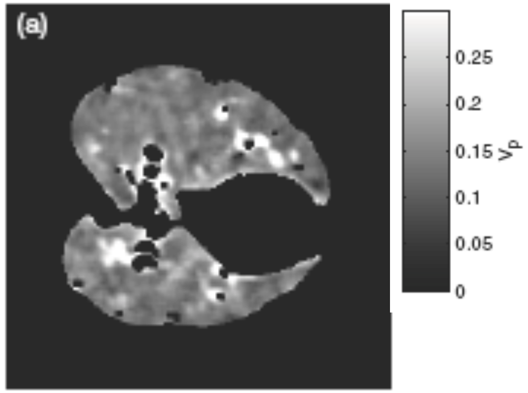
Bertrand et Coll. Eur Heart J. 2005

Brain Perfusion (rat)



Adam JF et Coll. J Cereb Blood Flow Metab. 2003

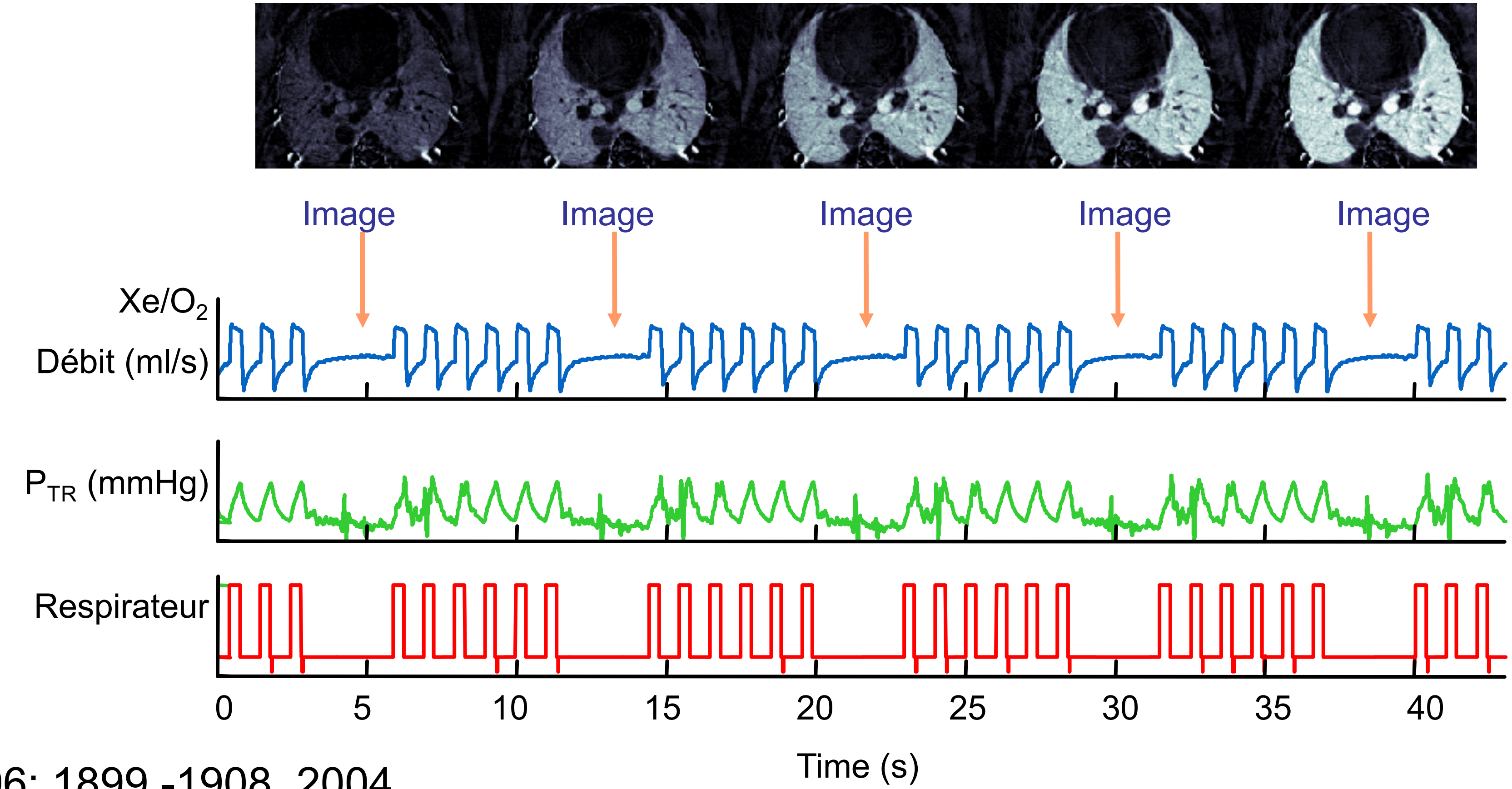
Lung Blood Volume (Rabbit)



Suhonen H et Coll. PMB. 2008

Dynamic KES-CT: regional lung ventilation

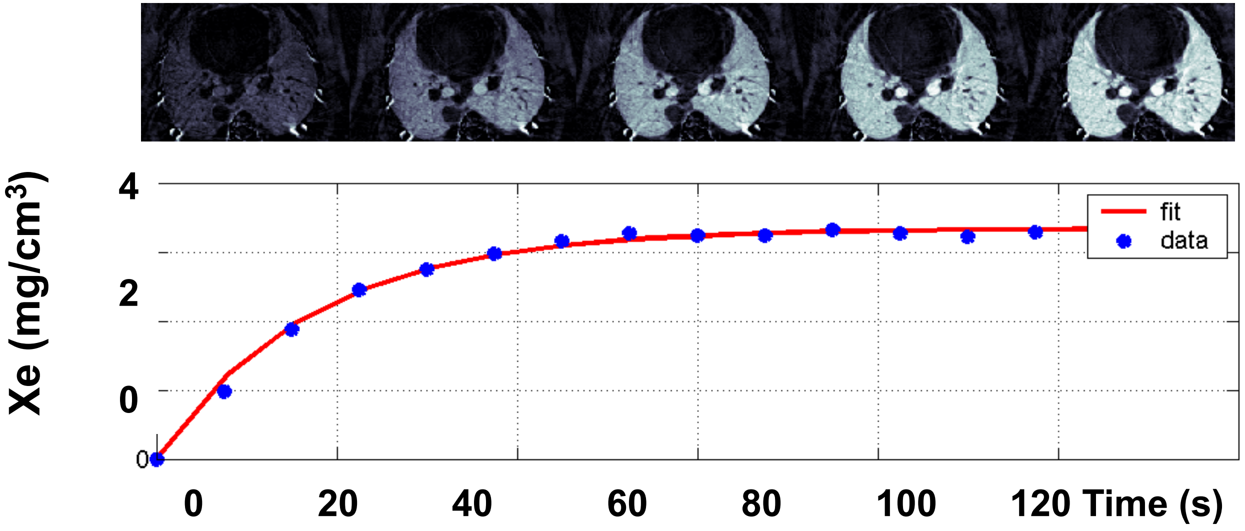
Lung Xe washin:

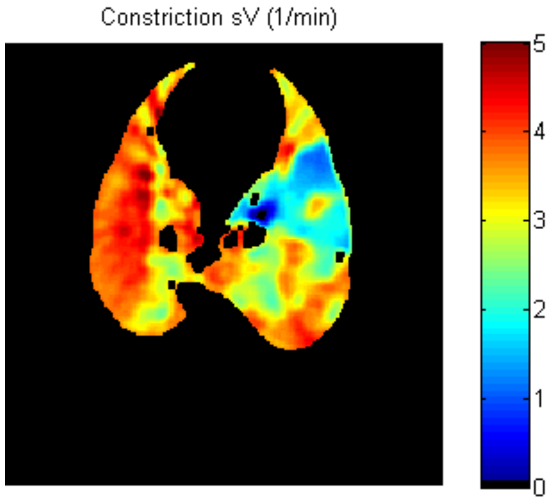


Porra et al. J Appl Physiol 96: 1899 -1908, 2004

Dynamic KES-CT: regional lung ventilation

- Time constant (τ) of Xe wash-in: $C_{Xe}=C_0(1-e^{-t/\tau})$
- Specific ventilation (sV) = ventilation/V_{voxel} : $sV' = 1/\tau$

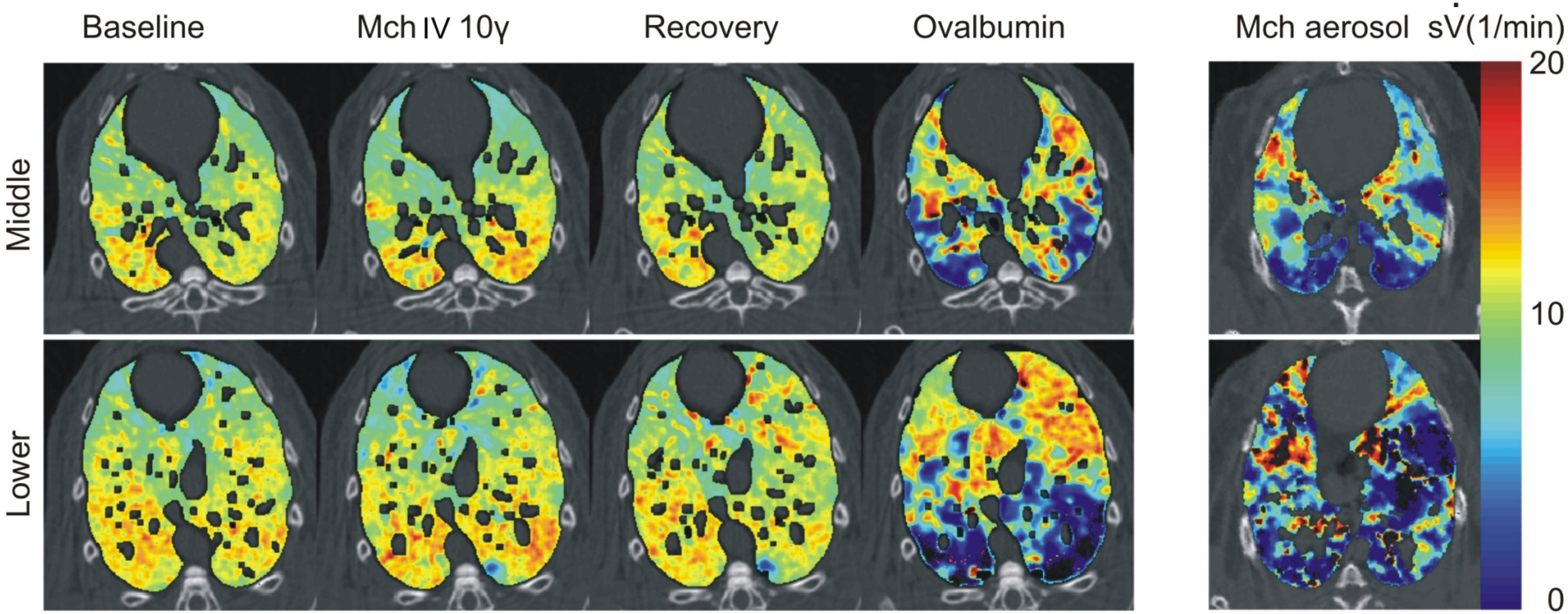




Simon BA, *J of Clin Mon Comp* 16: 433-442, 2000

Porra et al. *J Appl Physiol* 96: 1899-1908, 2004

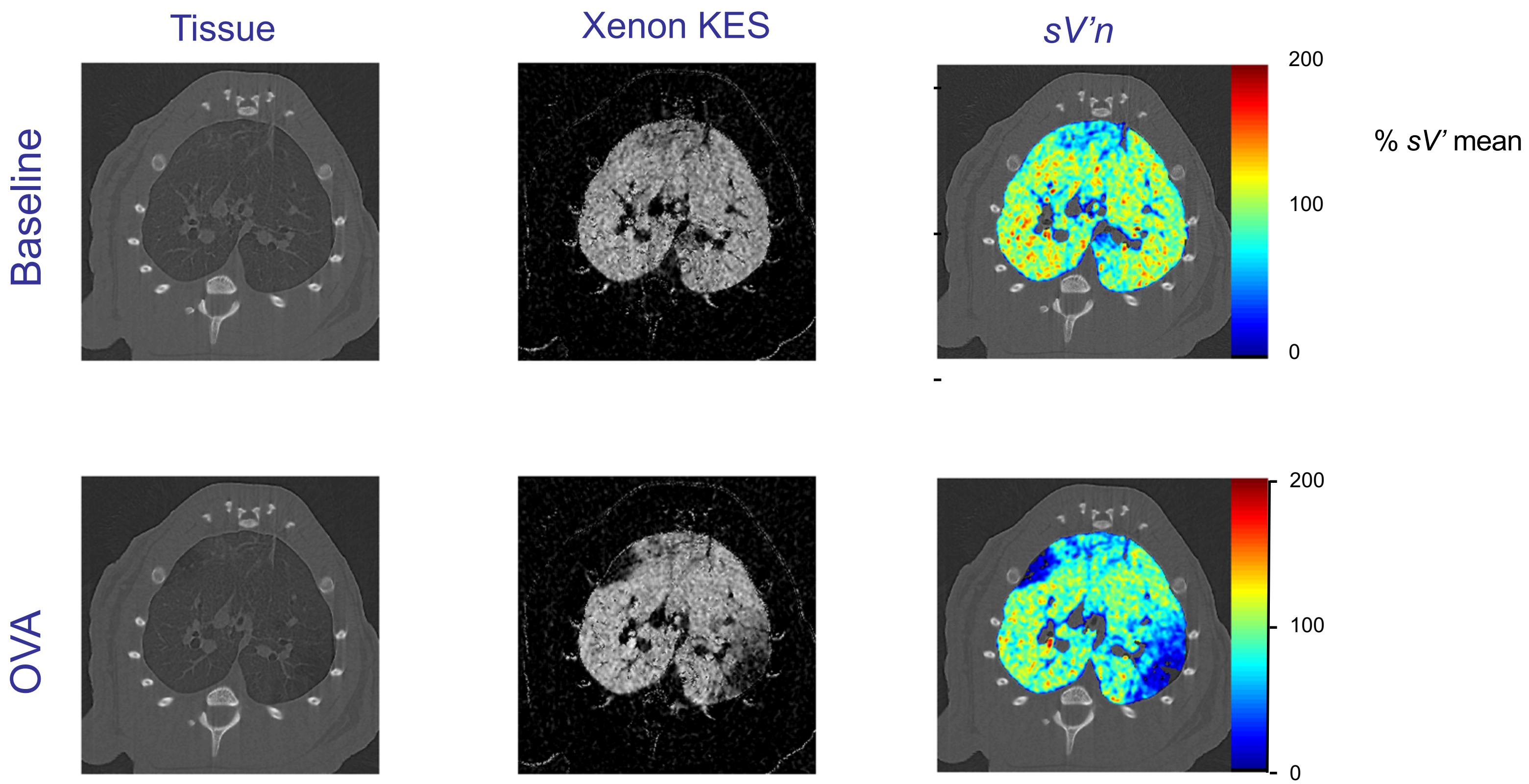
Regional ventilation distribution



Bayat S. et al. *Am J Respir Crit Care Med* 180: 296-303, 2009.

Spatial Resolution

- Best spatial resolution currently available for imaging regional lung function
  Pixel: 47 µm; 1800 projections;
  Acquisition time : 10 s



Layachi, S. et al. *J Appl Physiol* 115: 1057–1064, 2013

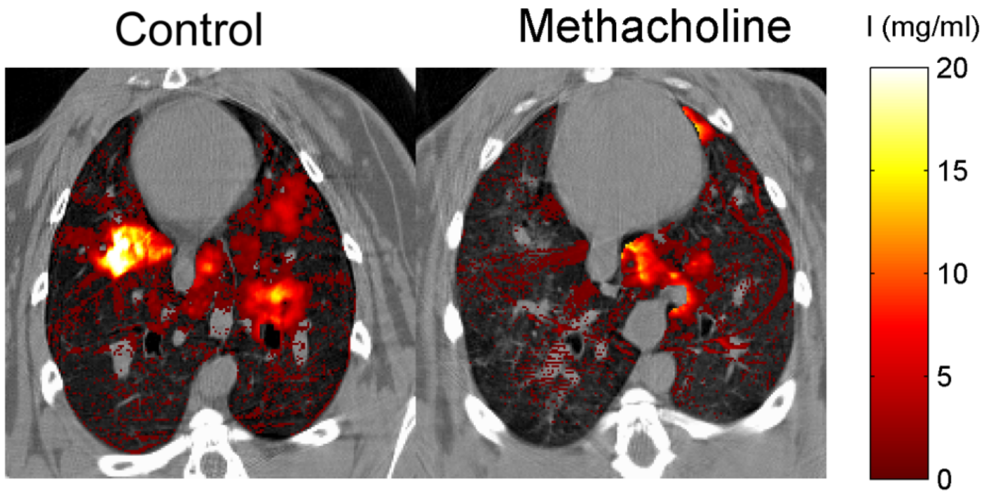
Results: regional ventilation

- Sample composite KES Iomeprol aerosol deposition in 2 representative animals

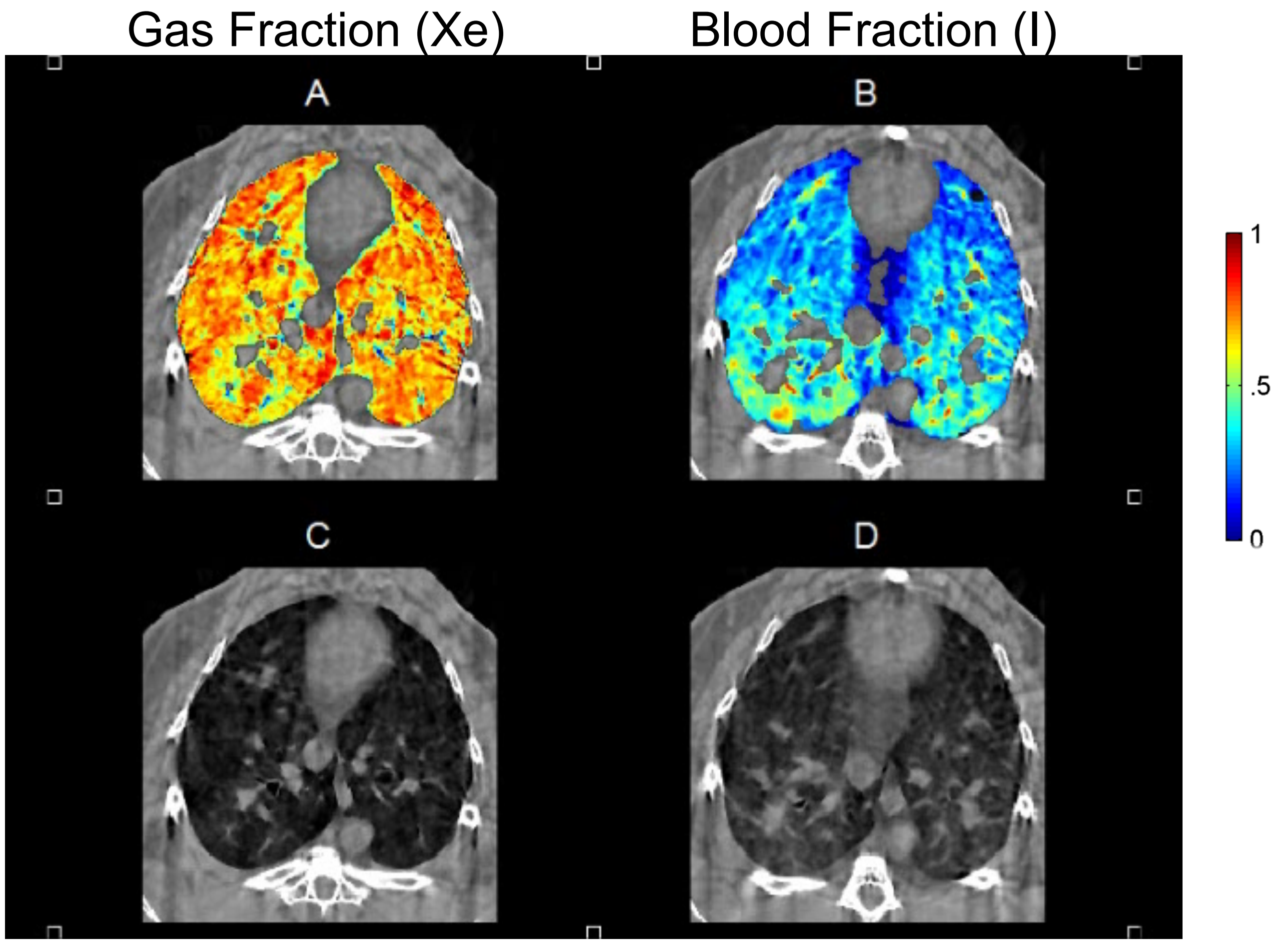
  Image voxel : 350×350×700 μm

  Acquisition time: 2 sec/image

  MMAD : 2.6 ± 0.1 μm



KES-CT of within-tidal changes in regional lung blood and gas

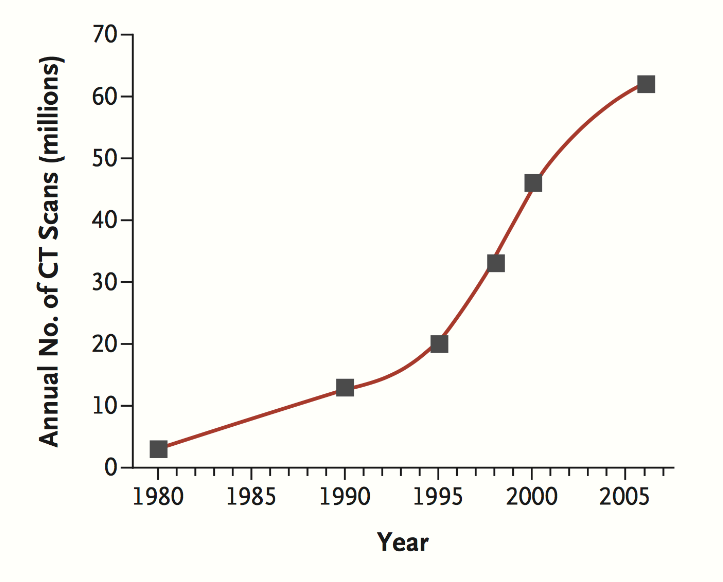


Porra L et al. *European Respiratory Journal* 44.Suppl 58 (2014): P543.

Patient Imaging at the European Synchrotron

Dose Issue

- 62 million CT exams performed each year in the USA
- the most frequently used 3D medical diagnostic tool
- Recent studies estimated that 3% of the cancers may be attributable to diagnostic CT[2]
- Cumulative dose of 50 mGy in childhood triples the risk of brain tumor and leukemia[3]



1 Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. *N. Engl. J. Med.* 2007;357(22):2277–2284.
2 De González AB, Darby S. Risk of cancer from diagnostic X-rays: Estimates for the UK and 14 other countries. *Lancet*. 2004;363(9406):345–351.
3 Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study. *Lancet*. 2012;380(9840):499–505

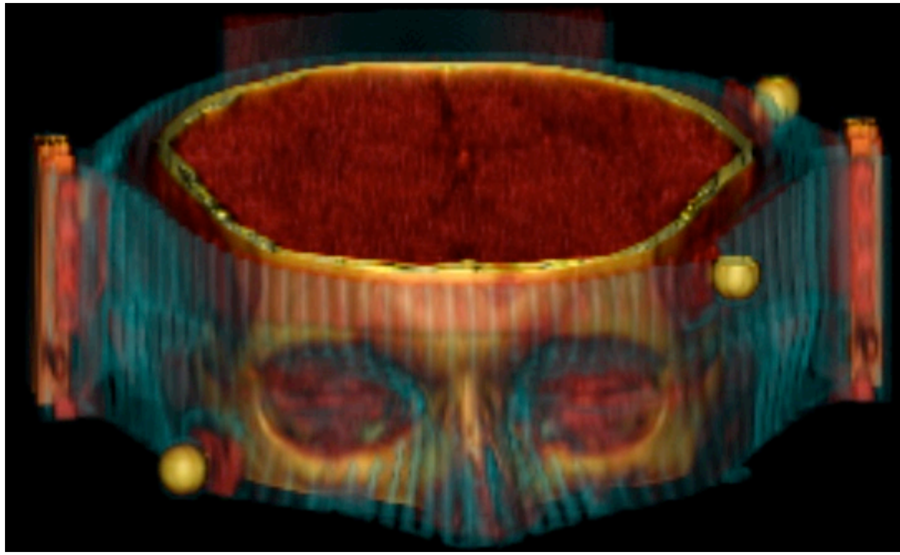
Imaging conditions

- Patient positioning tomography
  +/- post injection
  +/- 3D

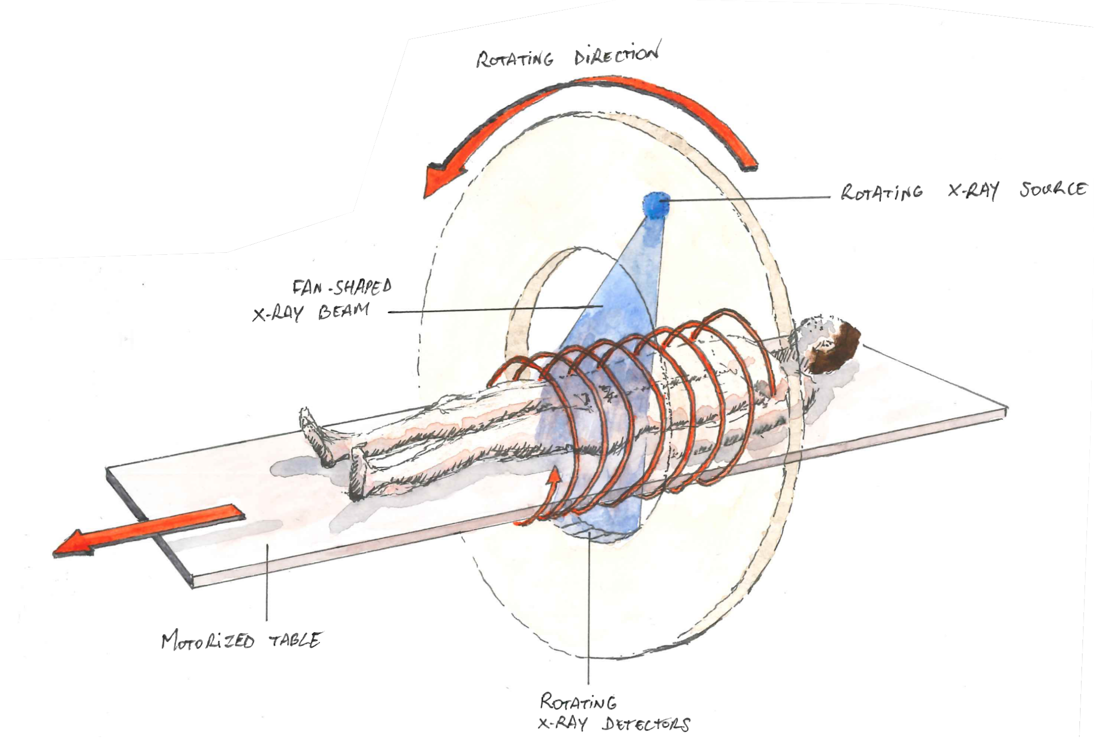
- Same beam used for radiotherapy
  Monochromatic (80 keV)
  Same flux but attenuated (14.5 cm PMMA)

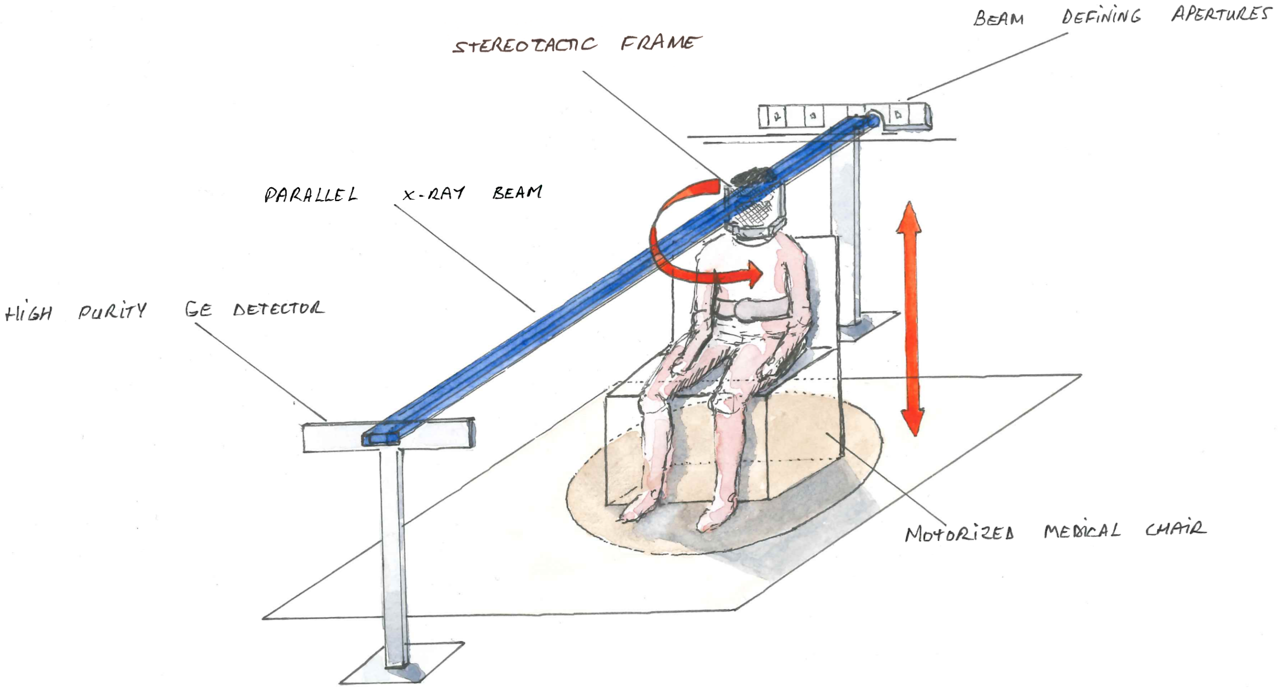
- Integration detector (HPGe)
  Pixel size 350µm * 1cm
  Bem collimated to 2mm (high) * 15 cm (width)

- Distance between patient and detector: 6m



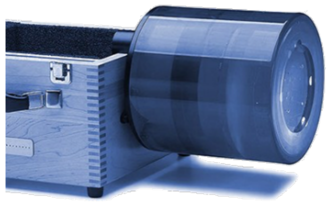
Geometry of acquisition





Comparison with hospital scanner

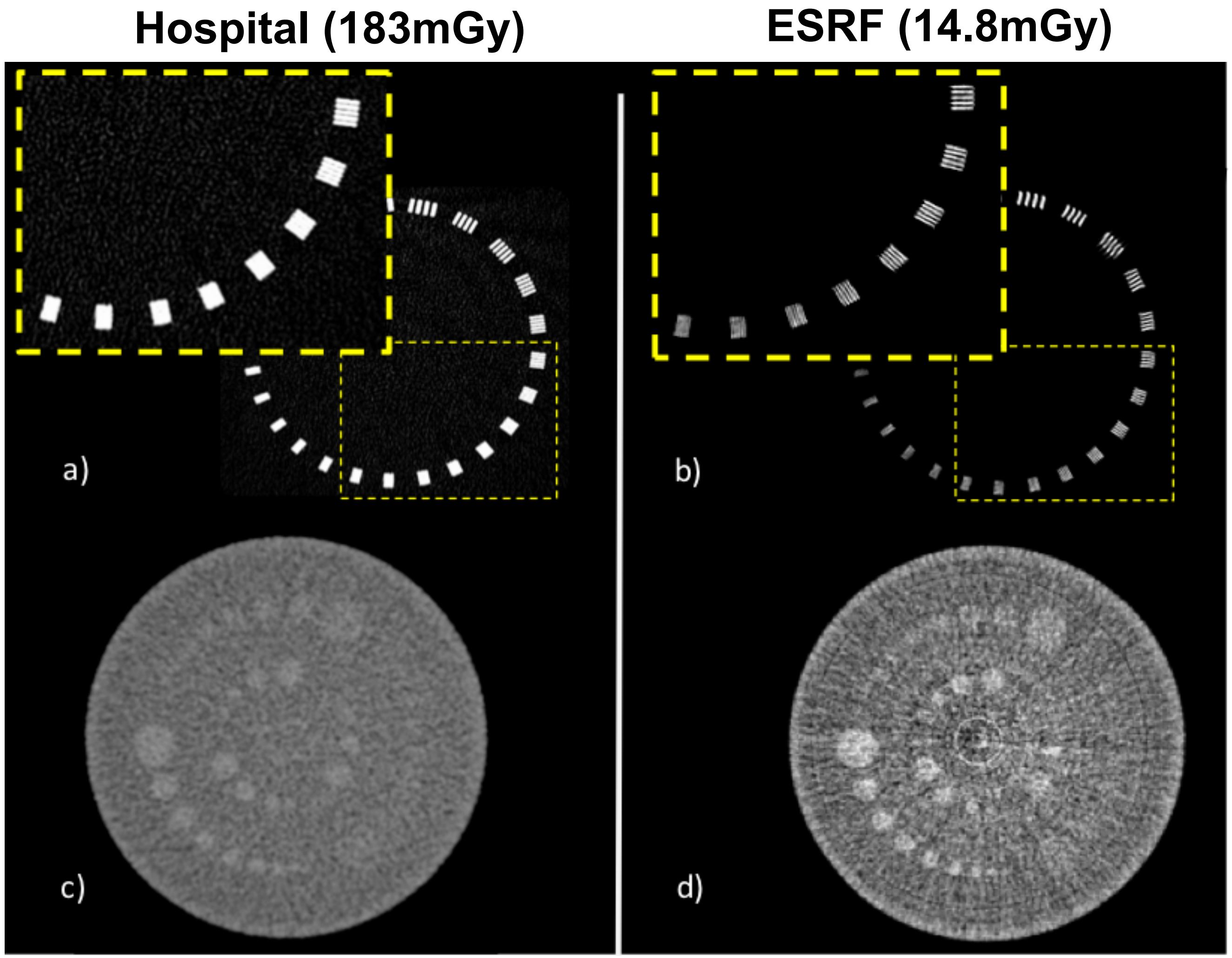
GE Revolution scanner



Catphan Phantom

Acquisition protocols		Energy	PMMA thickness (cm)	Slice thickness (mm)	Pixel size (mm)	Number of projections (-)	Dose CTDI (mGy)
Hospital	Standard head (patient)	120 kVp 250 mA	n.a.	1.25	0.44	n.a	33
	Inner ear (phantom)	120 kVp 350 mA	n.a.	0.625	0.44	n.a	183
ESRF	Patient acquisition	80 keV 191 mA	14.5	2	0.35	1024	93
	‘Low dose’ (phantom)	80 keV	18	0.625	0.35	340	14.8

Comparison with hospital CT



Quantitative Comparison

Acquisition protocols		CNR	SNR	MTF (pl/mm)	CTDI (mGy)
Conventional CT	Standard head	1.94	16.99	10	33
	Inner ear	1.26	10.33	11	183
ESRF	Patient acquisition	4.46	540.06	15	93
	'Low dose'	1.91	217.65	15	14.8