SPECT
IMAGING ALL THE PHOTONS

Spectral Photon Counting CT

Review of an initial pre-clinical experience with an experimental spectral photon-counting computed tomography system

4th workshop on Medical Applications of Spectroscopic X-ray Detectors, 2017

Presenter : Philippe Douek, Radiology , Lyon University, CERMEP/Creatis

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ACKNOWLEDGEMENTS

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Erasmus University, Rotterdam
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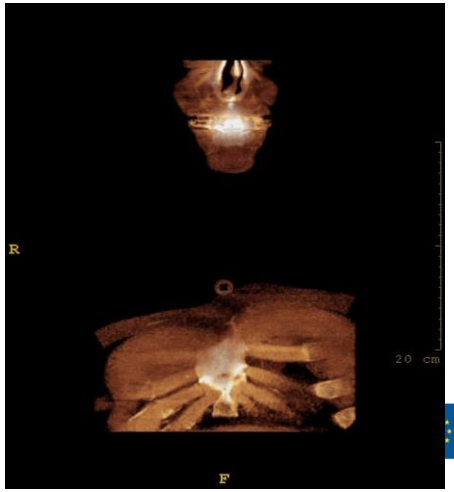
Funding from the European Union's Horizon 2020 No 643694.

Computed Tomography

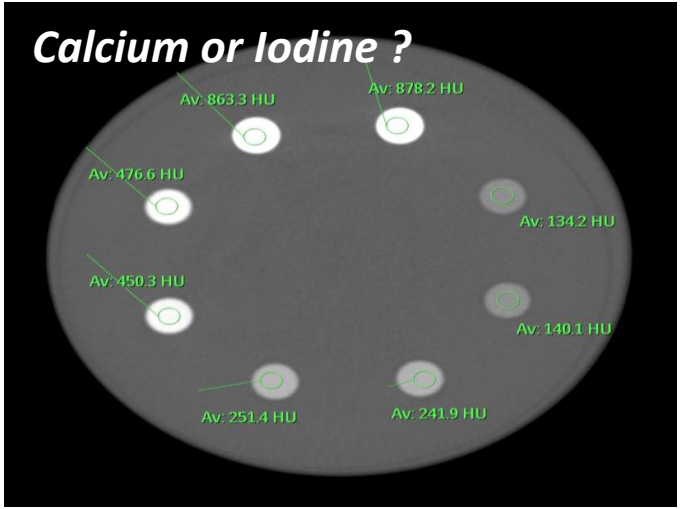
- CT key imaging modality widely used in the world
- CT scans performed worldwide per year is now numbered in the hundreds of millions
- CT: Majors improvements the last 10 years:
  - Large detectors:
    - Improved workflow with faster acquisitions
    - Improved diagnosis (PE, Stroke, Emergency Polytrauma etc..)
  - Iterative reconstructions
    - Reduced dose with improved S/N



Current CT Technology Limitations

- Contrast between different soft tissues is insufficient e.g. tumor detection, atherosclerotic plaque characterization
- Tissue-type specific quantitative CT imaging is not possible;
- High-resolution imaging is limited;
- Artifacts appear through polychromatic effects e.g. beam hardening.

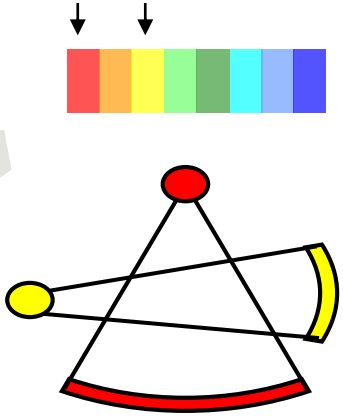
- Single X-ray acquisition cannot always help in the tissue characterization (finding out the contribution of each effect: photoelectric and Compton) and may lead to similar HU for different tissues



Patient care

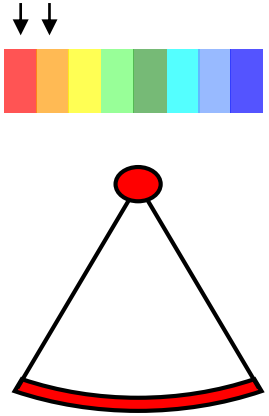
- More efficient and personalized thanks to development of targeted therapy
- Better detection, characterization of lesions and early assessment of treatment response are mandatory
- Need for
  - Improved detection:
    - small lesion<5mm and
  - Improved contrast to differentiate lesions components beyond levels currently achieved with CT and MRI
  - Accurate quantification of pathophysiological process

Technology Paths to Dual-Energy Acquisition



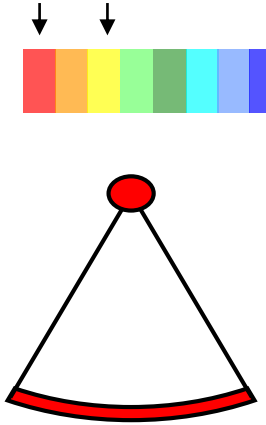
Dual Source

Spectral mode:
needs to be pre-selected
2 tubes (80 0r 100/140 kVp)
Image Space



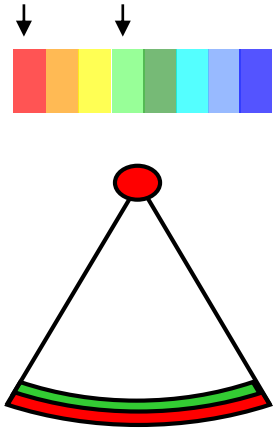
kV Switch

Spectral mode:
needs to be pre-selected
Fast kV switching: 80/140kVp
Projection Space
(interpolations)



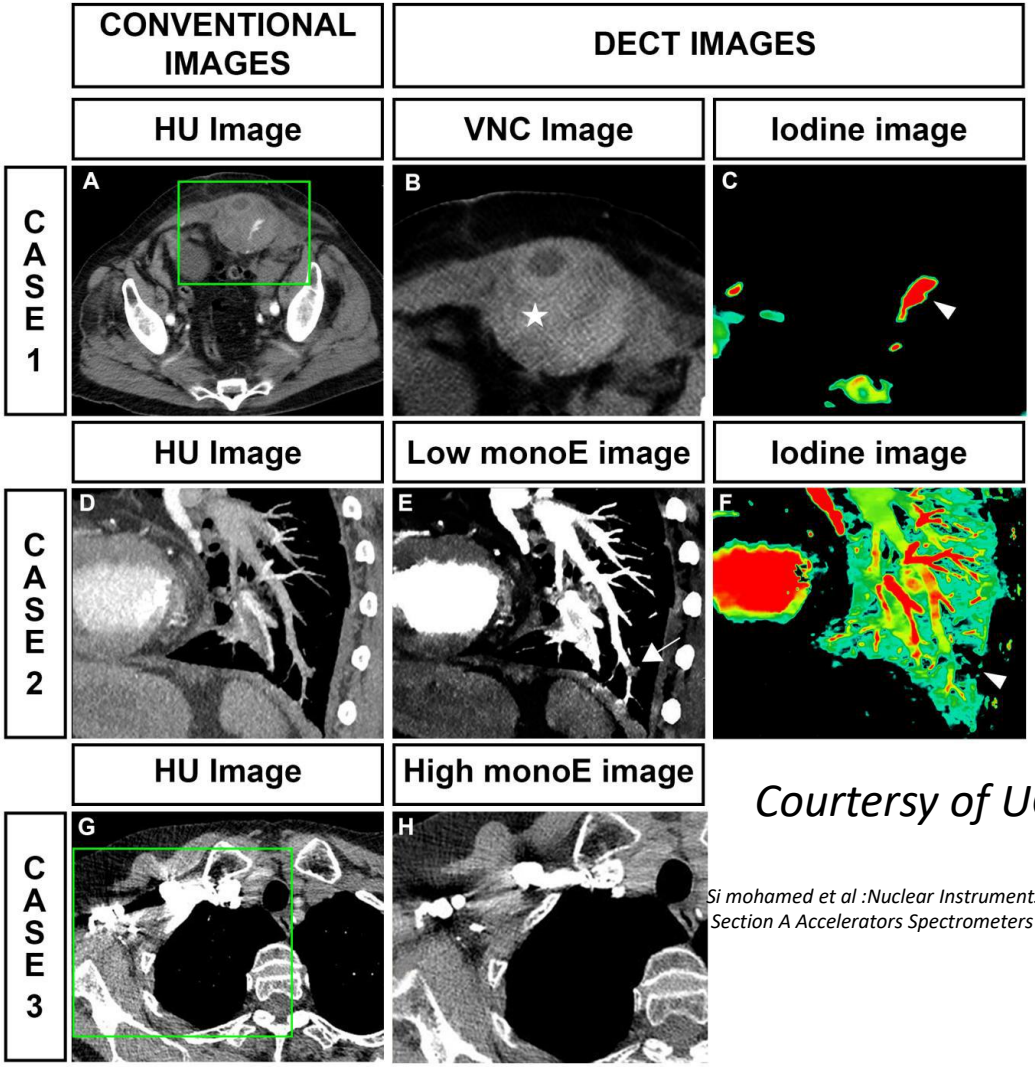
Dual Spin

Spectral mode:
needs to be pre-selected
1st spin @ 80kVp
2nd spin @ 140kVp
Image Space



Detection Based

No spectral mode:
SPECTRAL ALWAYS
@ 120 kVp & 140 kVp
Tube mA modulation
Dose Neutral
Projection Space



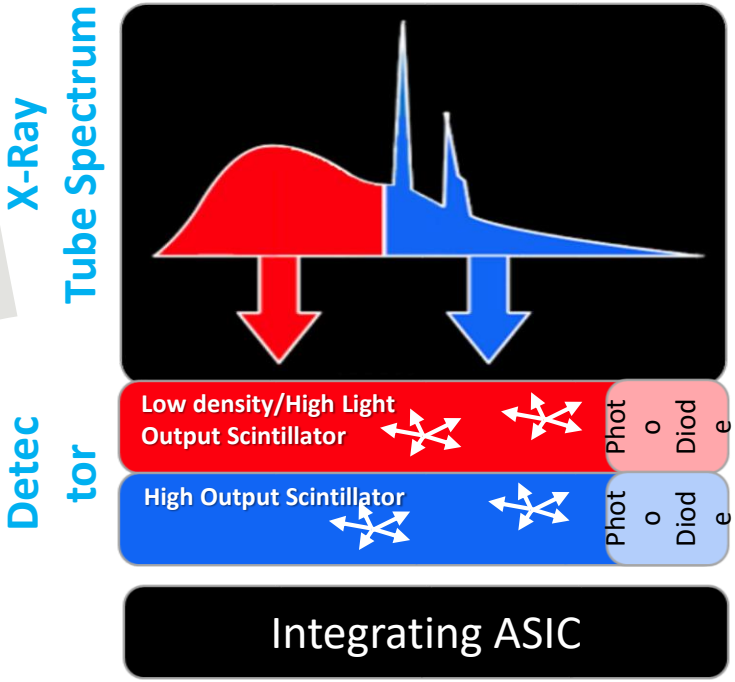
Courtersy of UCL

Si mohamed et al :Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment · April 2017

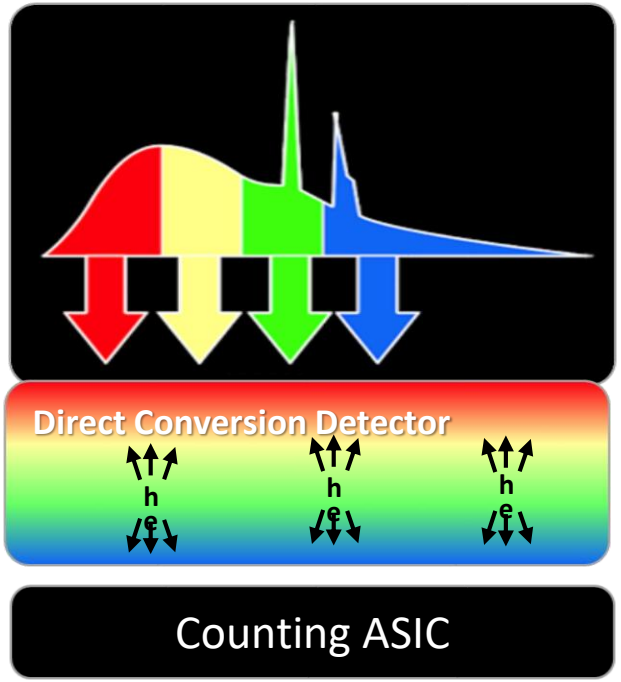
DECT Technology Limitations in the Accurate Formation of VNC/iodine Map Image Pairs

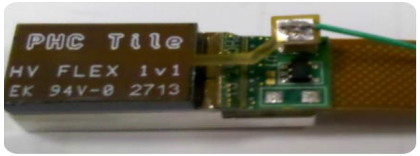
- the two energy spectra, emitted and/or detected, have significant overlap and only provide moderate energy resolution
- soft tissues contrast is insufficient
- dual-energy iodine maps are contaminated with attenuation arising from calcium-rich structures such as bones or calcifications

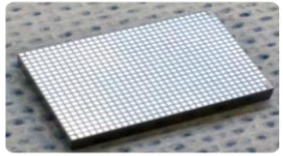
Dual Energy CT
Dual Layer Detector (PHILIPS)



Photon counting CT
Direct Conversion Detector







Goal

Improved diagnostic accuracy of CT

By using spectral photon counting x-ray detectors

X-ray Detector Technology  Clinical Applications

Photon - Counting System Pre Clinical Prototype

Specification

Parameter	Specification
Platform	Philips iCT
Supported scan modes	Axial ,Axial Cycles, Helical
Tube voltages [kVp]	80, 100, 120
Tube currents [mA]	10-100
Focal spot [mmxmm]	0.6 x 0.7
Gantry rotation [s]	0.75
Projections per rotation	2400
Number of focal spots	2
Z-coverage in iso-centre [mm]	2.5
FOV [mm]	158
Pixel Pitch [µm x µm]	500 x 500
Number of detector pixels	616 x 9
Readout electronic	Philips ChromAIX2 ASIC
Number of energy thresholds	5
Sensor Material	CZT, 2mm
Spatial Resolution [lp/cm]	> 20

Joint effort by Philips GRAD CT + Research.
System installed at University of Lyon, Prof. Douek, Prof. Boussel 2015

* For research applications only. Not available for clinical use.

Spectral CT Potential Benefits

- Improved Spatial Resolution

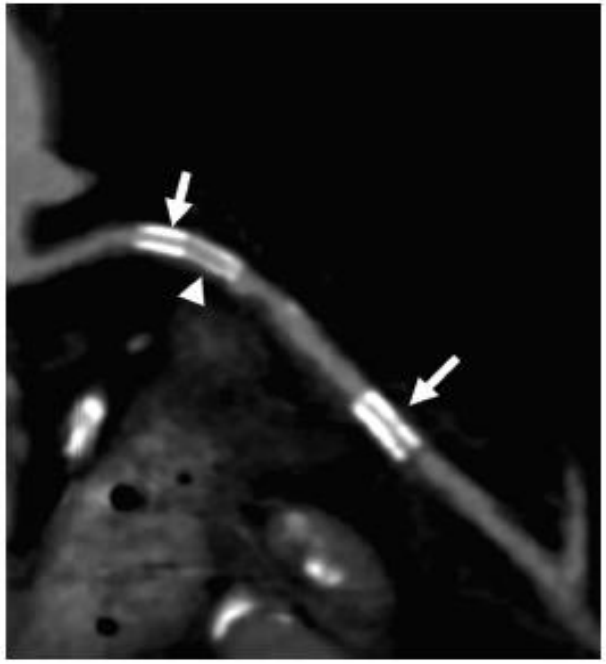
- K-edge imaging and multiple material characterization enabling simultaneous multi-agent imaging
  - Thanks to multibins ajustable thresholding and precise energy separation

SPATIAL RESOLUTION

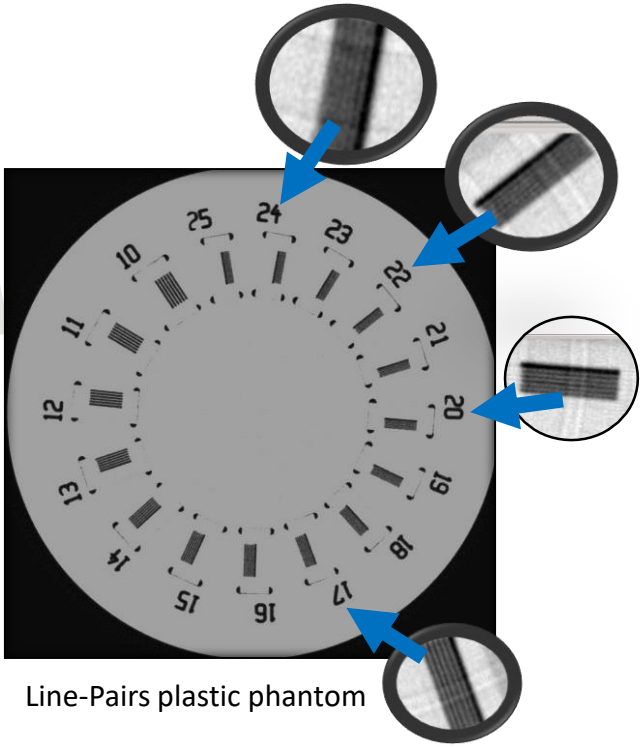
Added benefit

Benefits for Stent Imaging

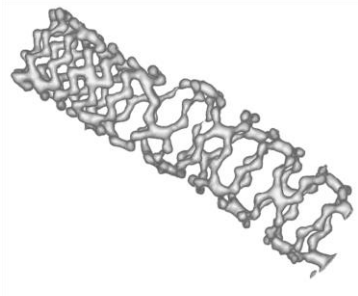
- Treatment of coronary atherosclerosis involves **metallic stent** placement
- Metal related **blooming artifacts** impair diagnosis of **in-stent restenosis**

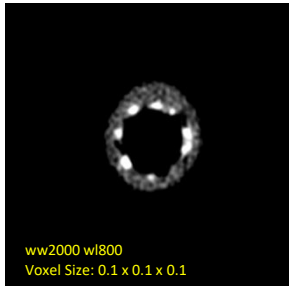


Spatial resolution -> Stent Imaging

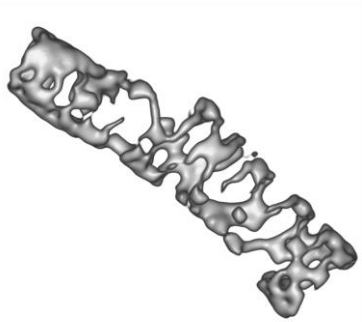


Line-Pairs plastic phantom



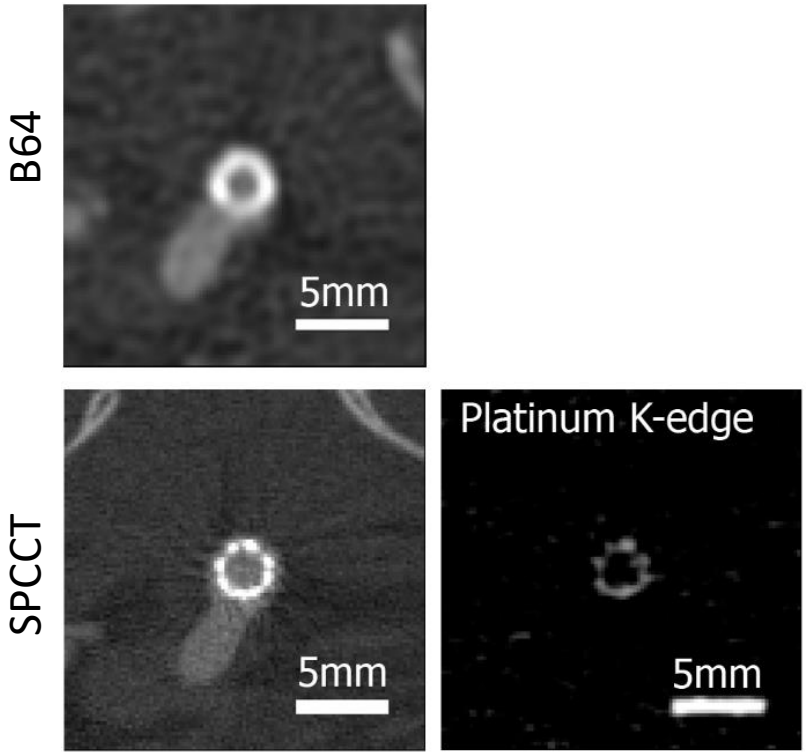


SPCCT



Standard CT

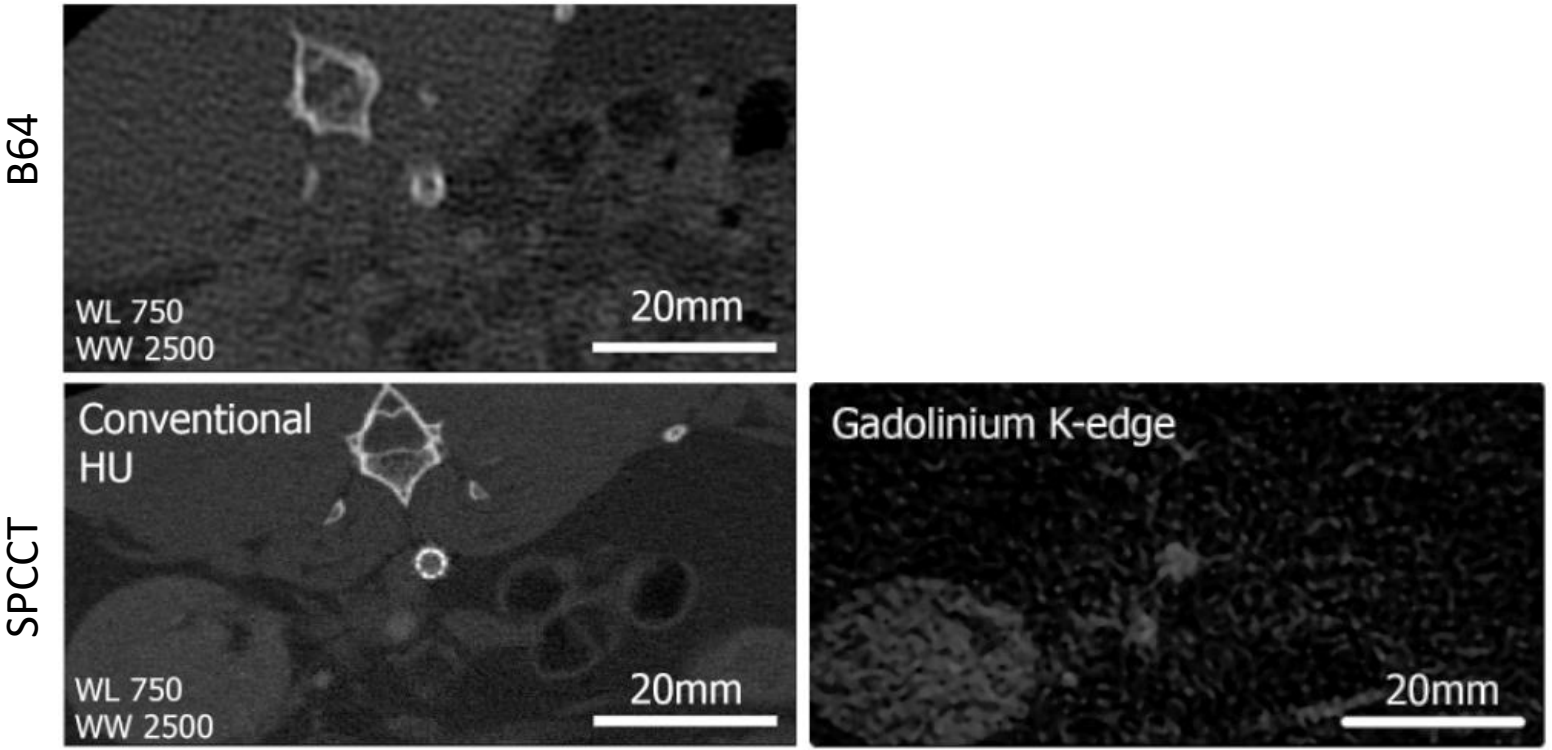
RESULTS : IN VIVO IMAGING WITH IODINE



(1pix gaussian filter)

Sigovan et al RSNA 2016, Initial experience in improving stent analysis and intra stent lumen assessment using Spectral Photon Counting CT and K-edge imaging

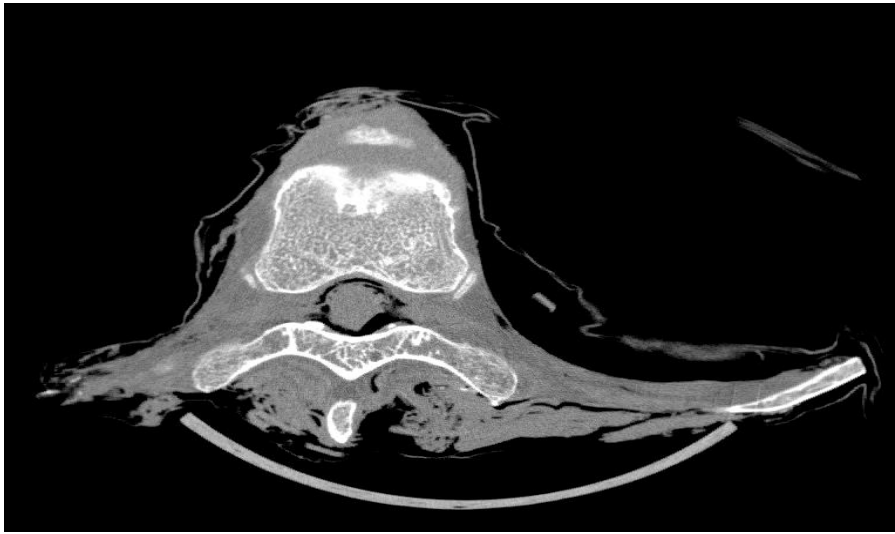
RESULTS IN VIVO IMAGING WITH GADOLINIUM



(1pix gaussian blur)

SPATIAL RESOLUTION

TECHNISCHE UNIVERSITÄT MÜNCHEN



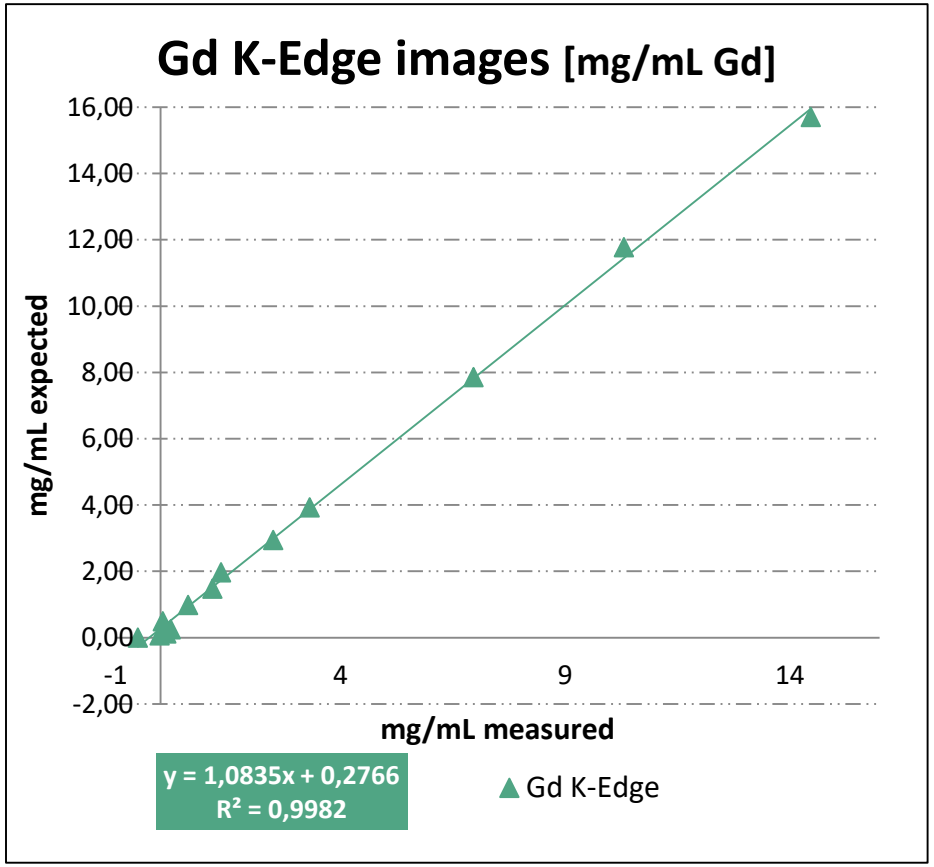
Scan of a human vertebra

SPECIFIC CONTRAST IMAGING

ADDED BENEFIT

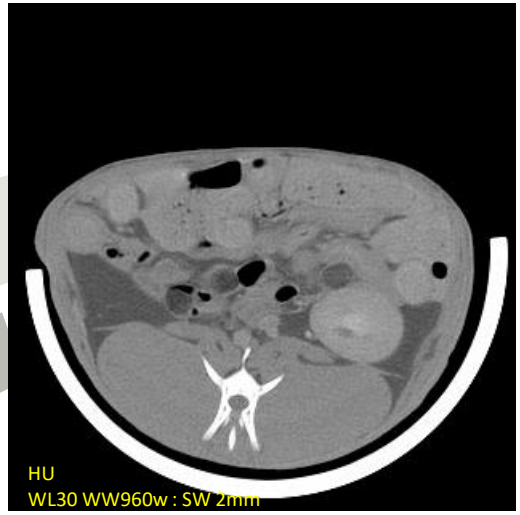
ADDED BENEFIT

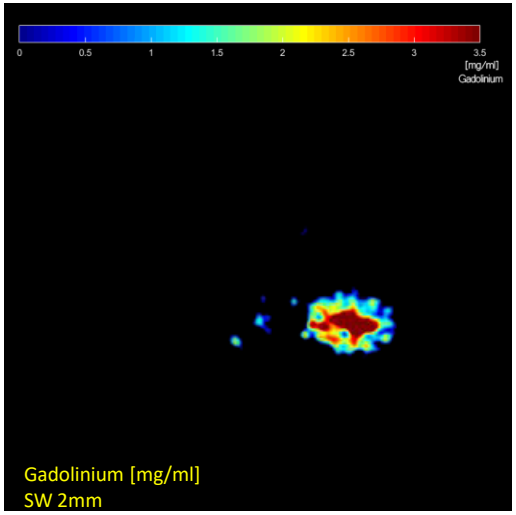
- Quantification organ perfusion for treatment planning
- Dual contrast for imaging combined pathophysiological processes
- multiple phase imaging for dose reduction
- Specific CM for dedicated imaging of diseases

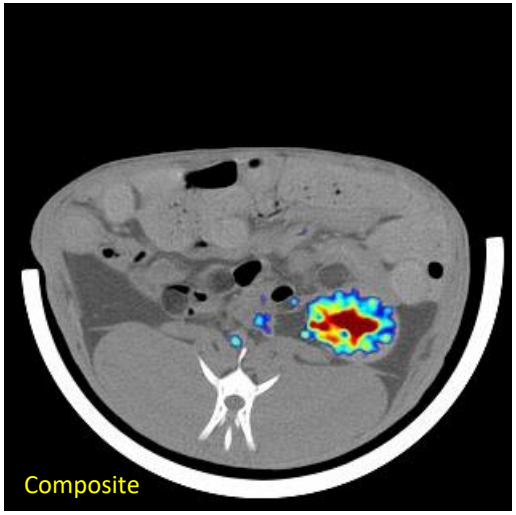


These graphs show the correlation between expected concentrations (densities) to the measured concentrations on SPCCT for Gadolinium using kedge imaging.

Gd Contrast Kidney Quantification





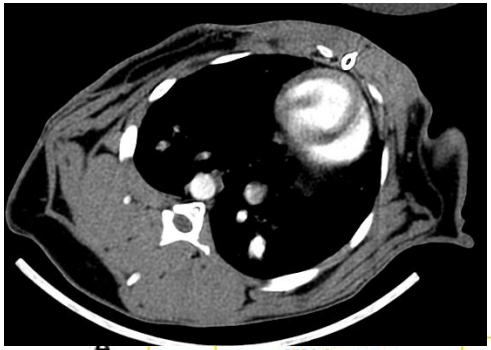


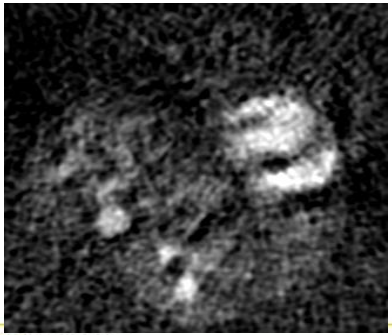
Cavity : 2.92 [mg/ml]
Parenchyma: 1.63 [mg/ml]

HU IMAGES : Cardiac angiography after dynamic injection of Gold (T1) (gif)

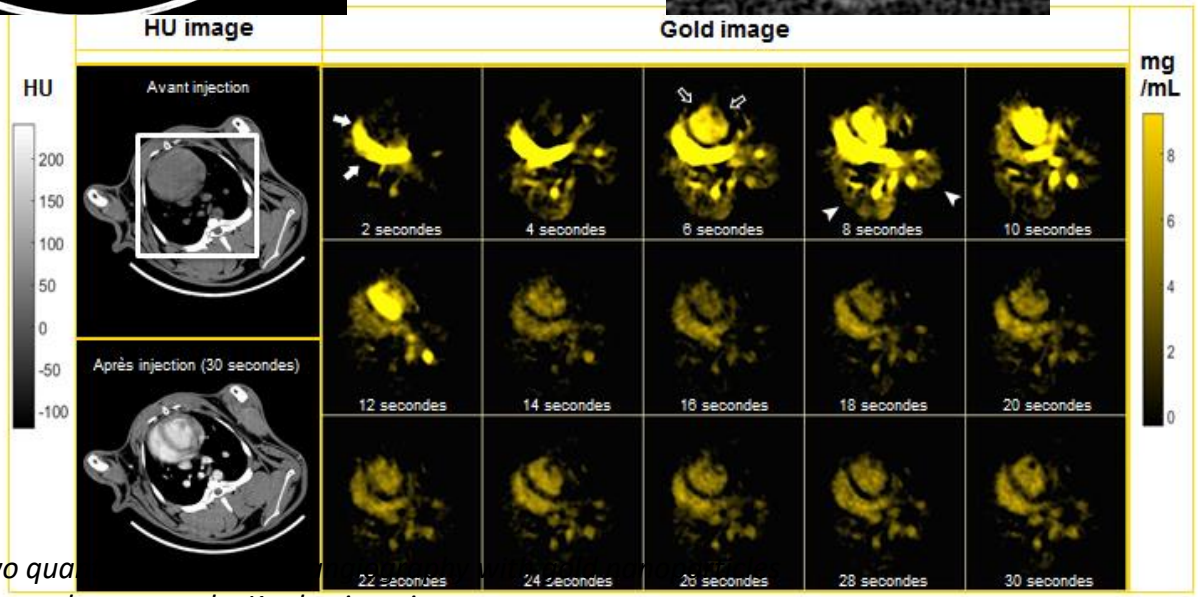
GOLD IMAGES : Cardiac angiography after dynamic injection of Gold (T1) (gif)

Parameters :
- Thickness 2 mm
- No Filter
- L1172; W311



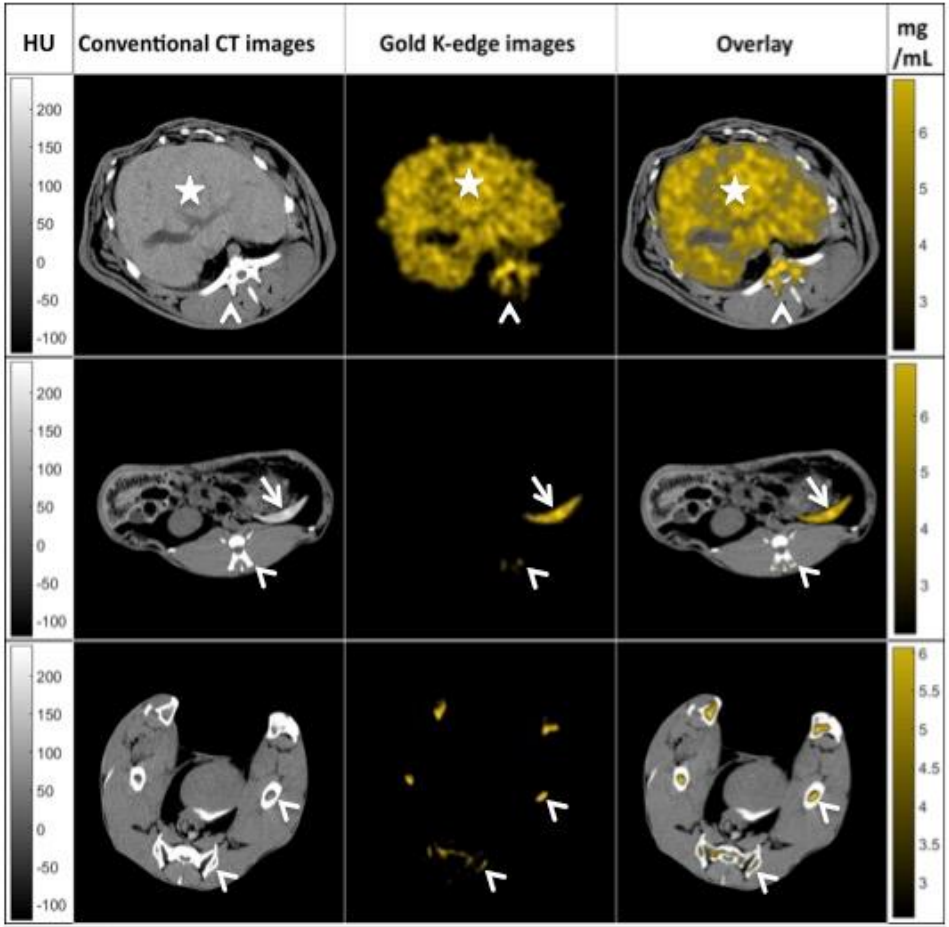


Parameters :
- Thickness 2 mm
- Gaussian filter 2 mm



Si-Mohamed et al RSNA 2016In vivo qua
and spectral photon-counting computed tomography K-edge imaging

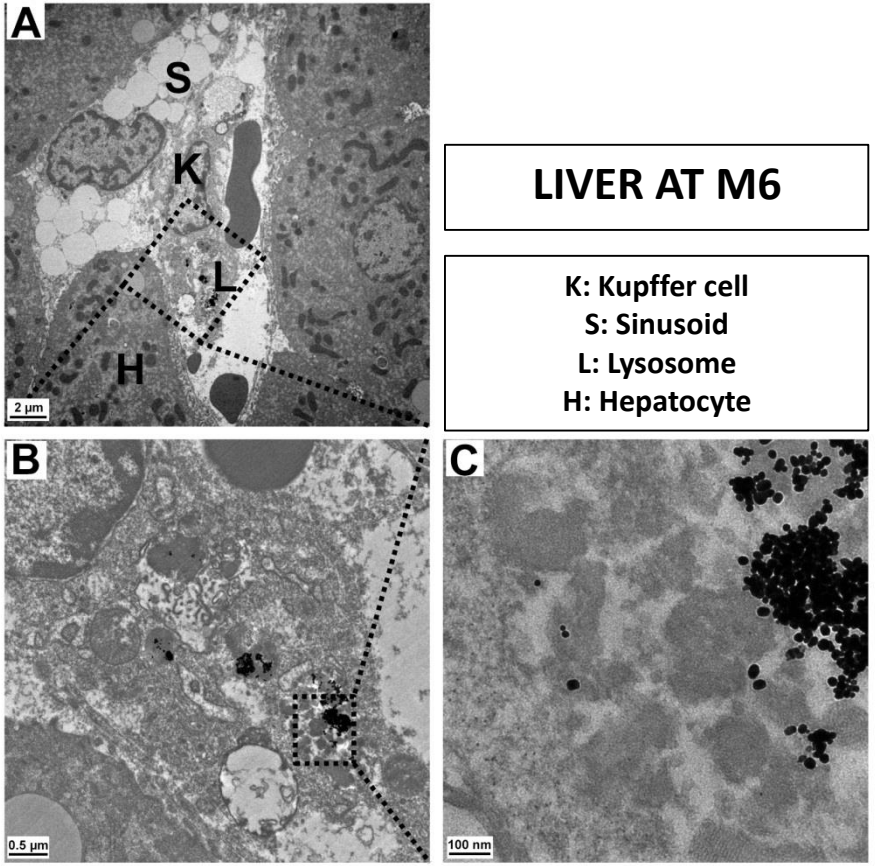
Cormode et al RSNA 2016, In vivo quantification of gold nanoparticles biodistribution kinetics with spectral photon-counting computed tomography K-edge imaging



RESULTS

- Uptake in the organs of the MPS
  - Bone marrow
  - Liver
  - Spleen
  - Lymph node
- Aggregation in the macrophages[(1)]

(1) Naha PC et al. Toxicol. In Vitro. 2015

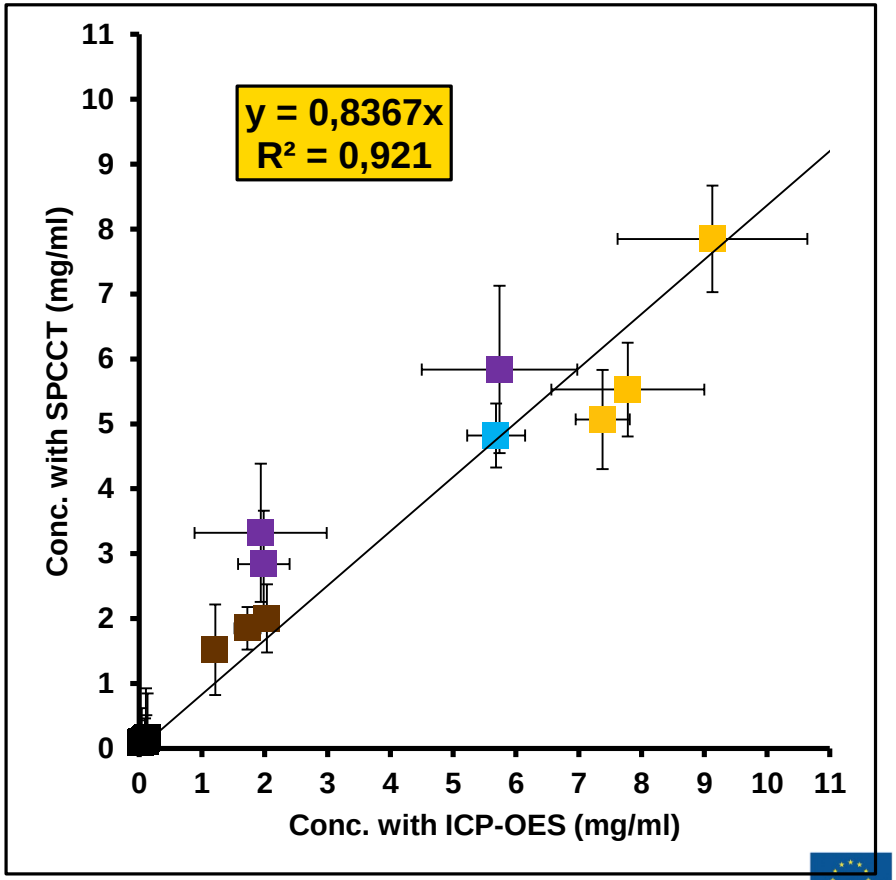


LIVER AT M6

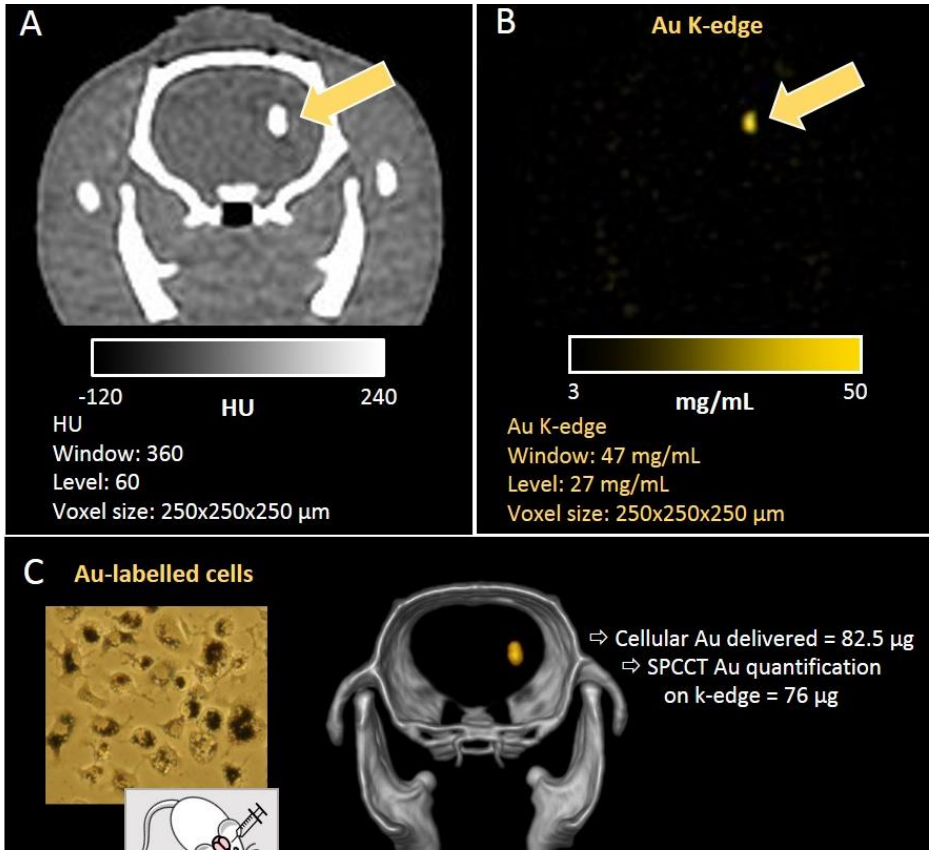
K: Kupffer cell
S: Sinusoid
L: Lysosome
H: Hepatocyte

RESULTS

- Spleen
- Lymph node
- Bone marrow
- Liver
- Kidney, heart, brain, blood



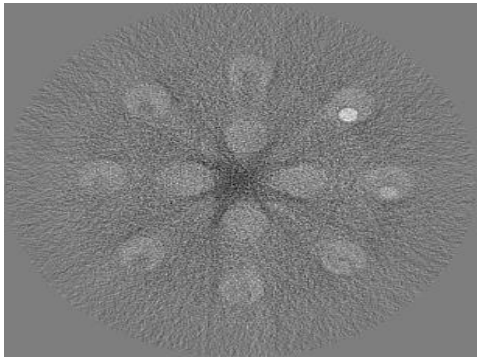
NON-INVASIVE IMAGING OF TRANSPLANTED THERAPEUTIC CELLS IN THE INFLAMED RAT BRAIN BY SPCCT

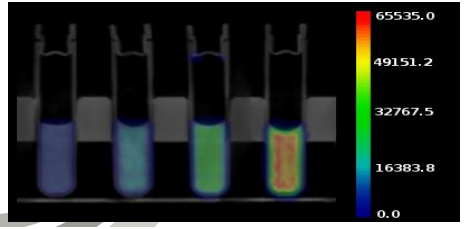


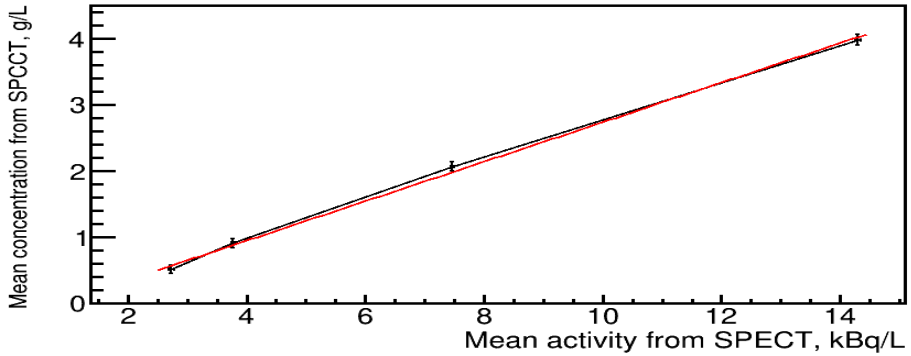
Postdoc of Ellsa Cucione (supervision Marlene Wiart)

PHYSICANCER SPEDIV: QUANTIFICATION OF GD NANOPARTICLES COMPARISON OF SPECT AND SPCCT

In-vitro results:

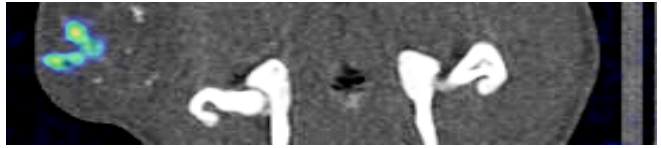


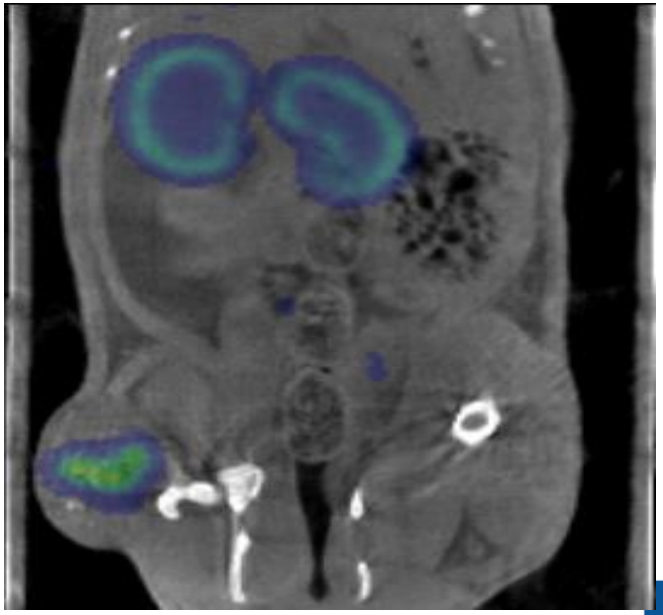




PHYSICANCER SPEDIV:
COMPARISON OF SPECT AND SPCCT

In-vivo evaluation on-going
in rats with chondrosarcoma
injected with AguiX NPs





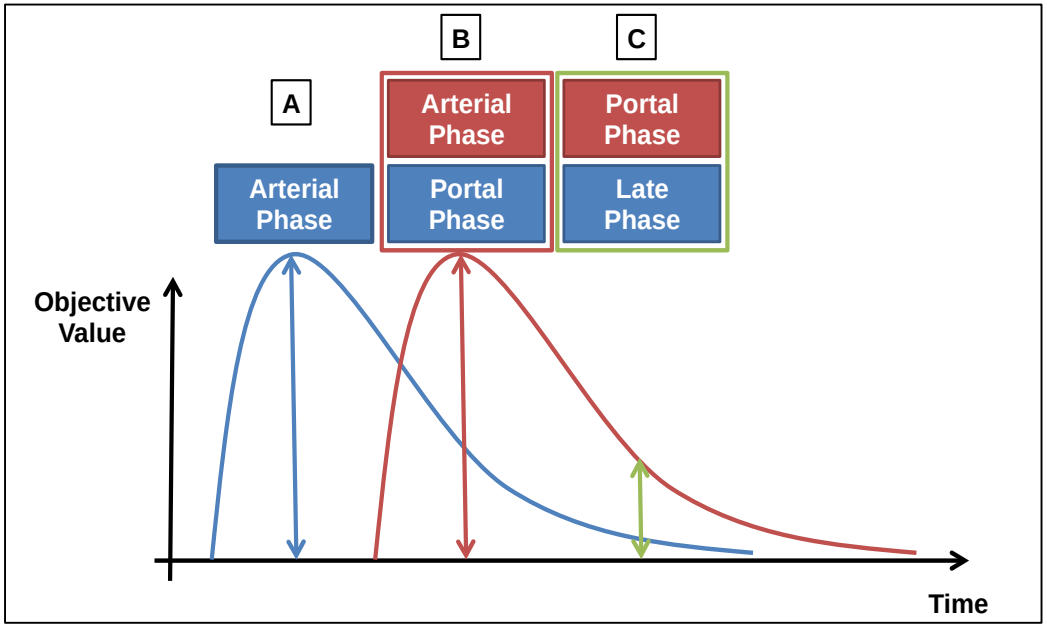
Postdoc of Olga Kochebina (supervision David Sarrut)

MULTIPHASE MULTICONTRAST IMAGING

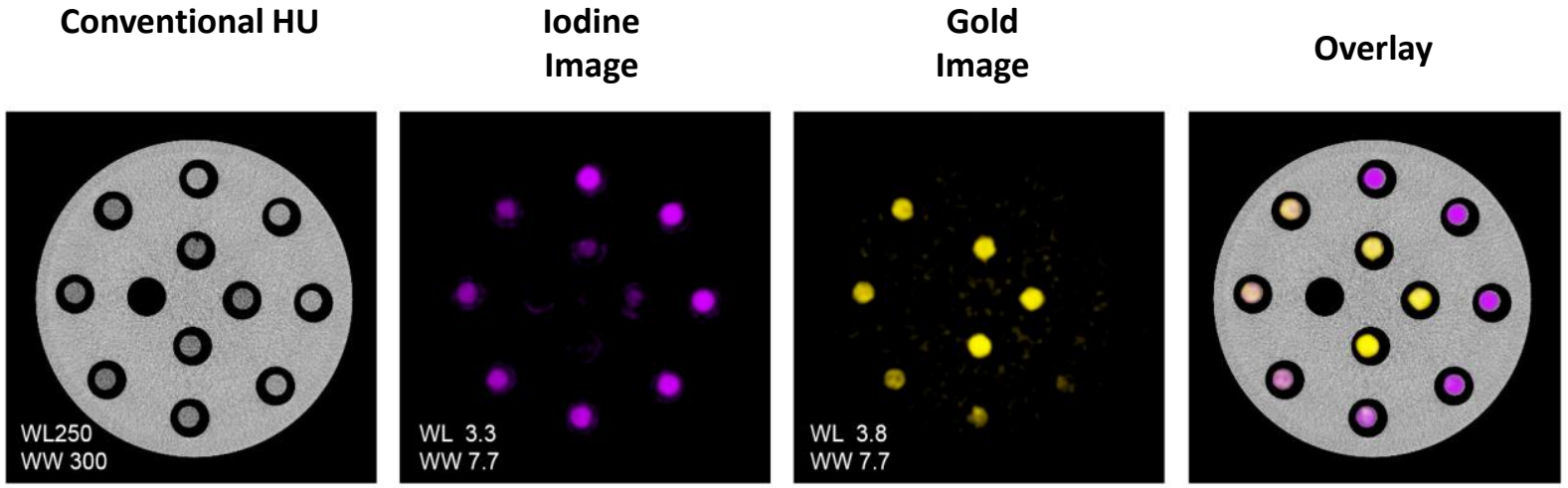
Added benefit

Multiphase imaging

- advantages of SPCCT is to image multiple contrast agents simultaneously due to specific discrimination
- multiple uptake phases of a given tissue/organ
- IMPACT FOR CLINICAL IMAGING

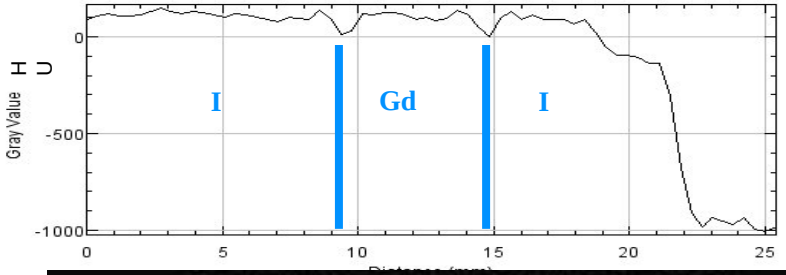


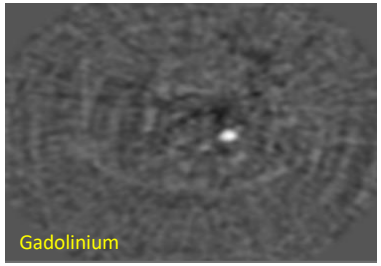
MIXED CONTRAST: IN-VITRO

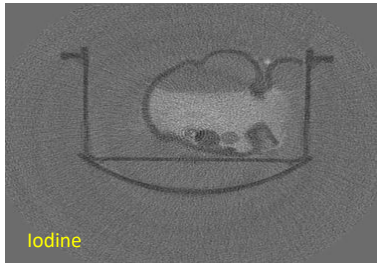


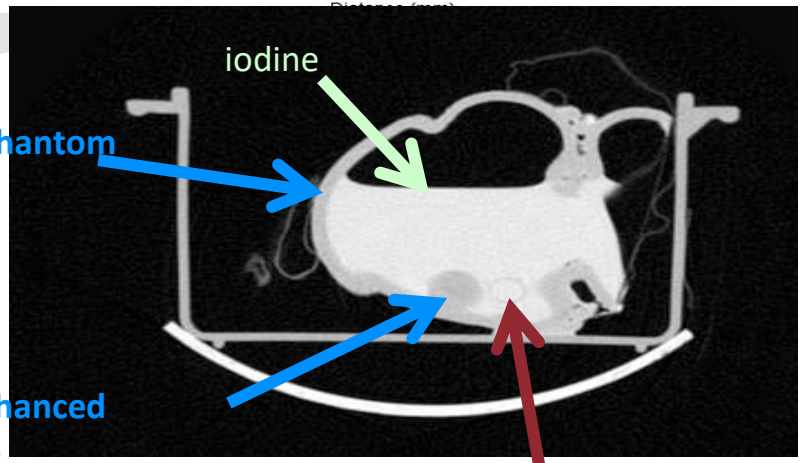
Bar-ness et al RSNA 2016

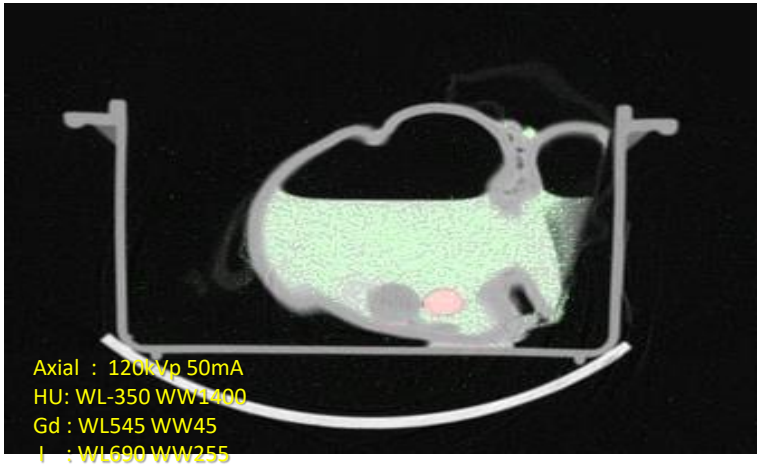
MATERIAL DECOMPOSITION *Contrast Specificity Images*
APPLICATIONS OF DUAL CONTRAST AGENTS











POTENTIAL FOR PERITONEAL IMAGING

SPCCT with K-edge imaging is feasible using dual contrast agents within peritoneal and blood compartments allowing a good assessment of the peritoneal cavity in rats.

SPCCT can be used to perform a complete peritoneal dual contrast protocol using K-edge imaging which has potential to investigate peritoneal metastases.

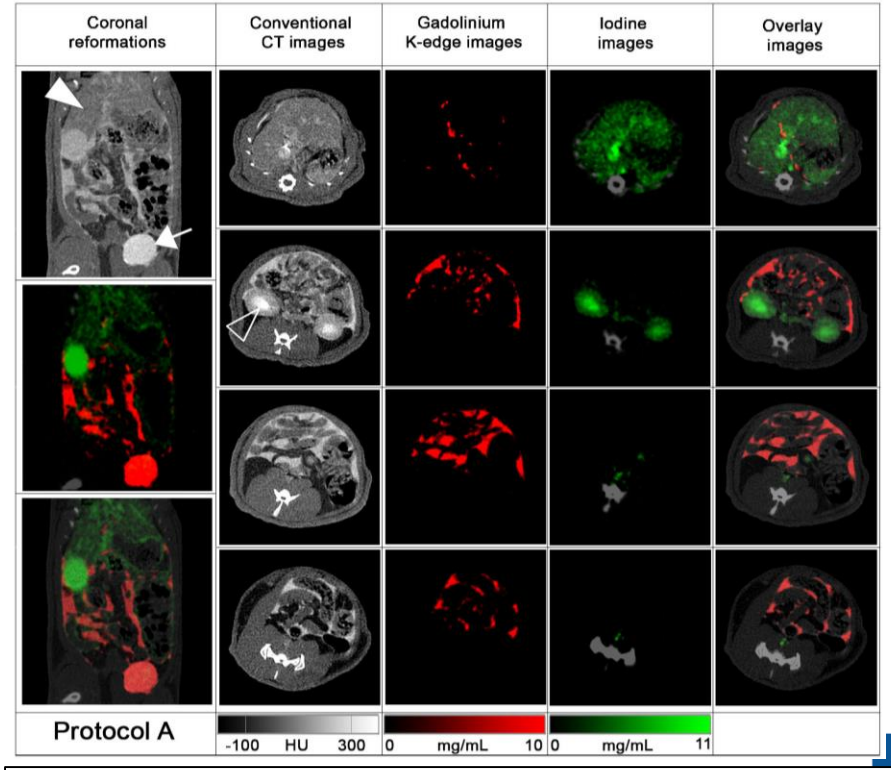
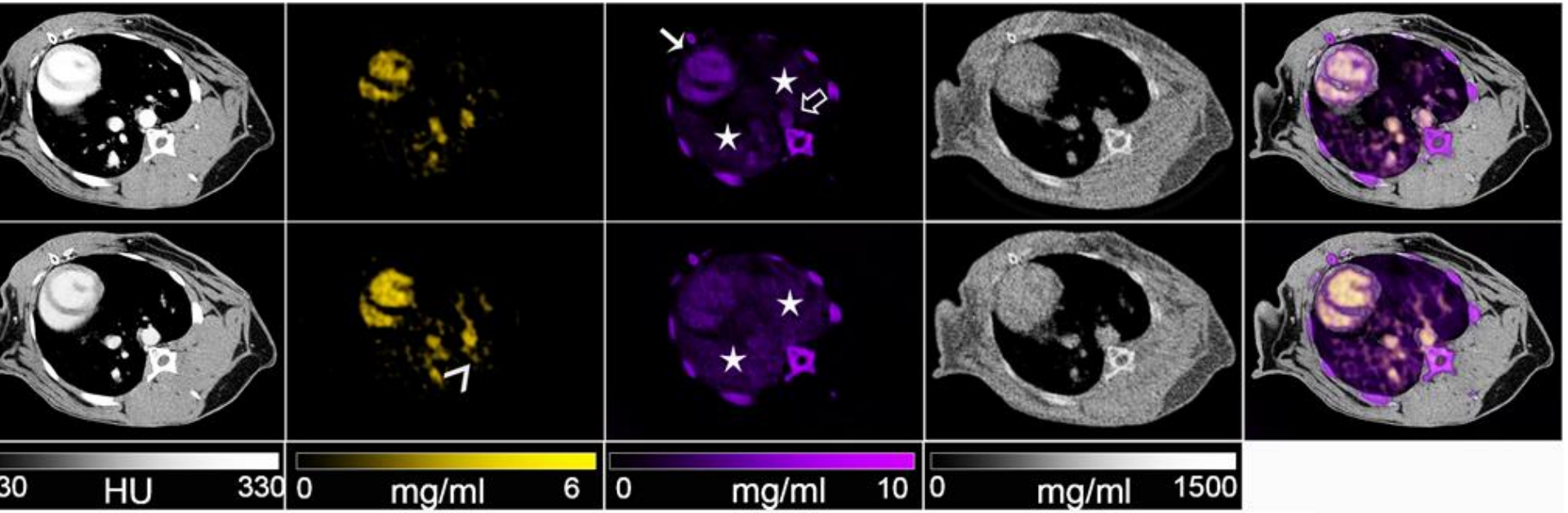


Figure 1 Photon-counting CT images depicting the abdomen protocol imaging.
(contrast agents: red/green, bone:grey, organs of interest: arrow=bladder, full head arrow=liver, empty head arrow=renal pelvis).
Protocol A : Spectral CT images of the peritoneal cavity with intraperitoneal injection of gadolinium and intravenous injection of iodine.

SPCCT IMAGES 25 MINUTES AFTER INJECTION OF BLOOD POOL CONTRAST AGENT (AUNP) AND 30 SECONDS AFTER INJECTION OF IODINE:

I ACQUISITION, 3 DIFFERENT IMAGES



Conventional Images:
Aorta and cardiac chambers enhanced without discrimination of CM

Gold K-edge Images:
only Blood pool enhancement

Iodine map.
Pulmonary enhancement
Lack of discrimination of Ca and iodine

SPCCT MULTIPHASE IMAGING

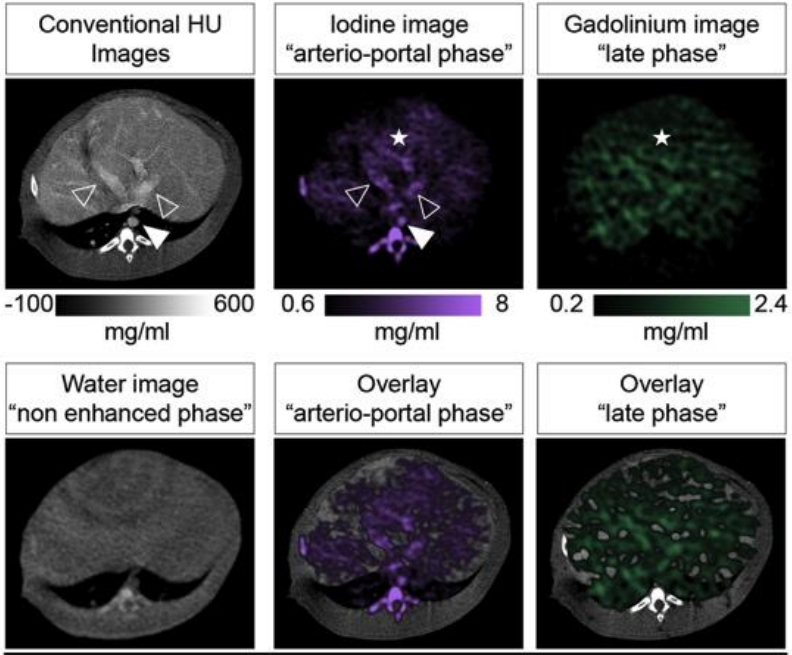


Figure. Liver multiphase imaging with a spectral photon-counting CT using dual contrast imaging.
Acquisition at 20 seconds after injection of an iodine contrast agent and 92 seconds after injection of a gadolinium contrast agent (star: parenchyma, full head arrow: aorta, empty head arrow: hepatic veins).

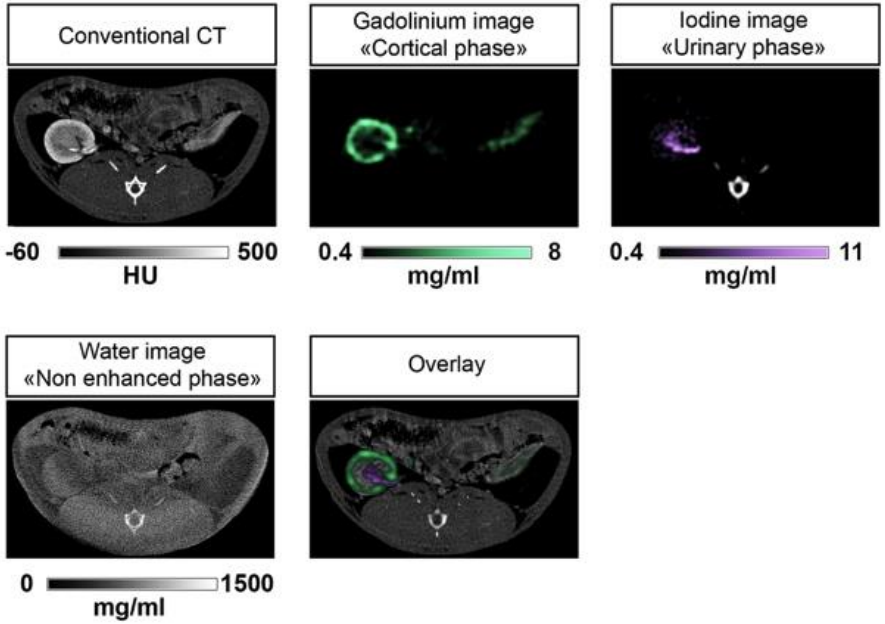
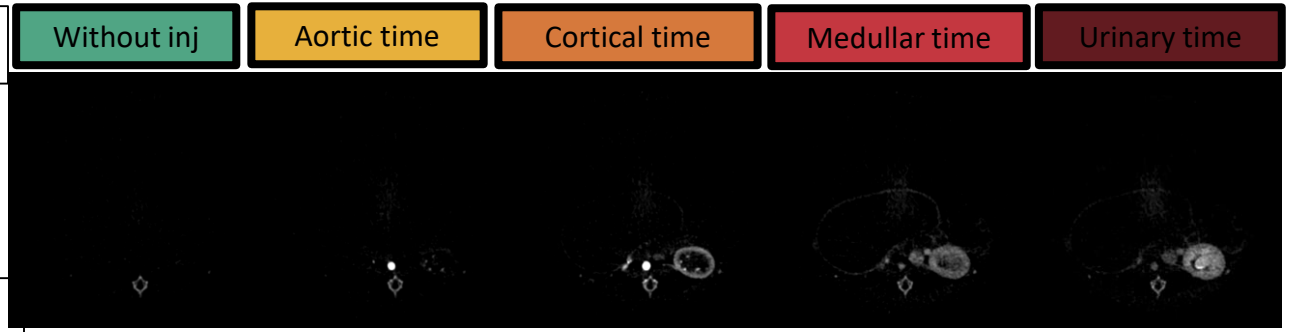


Figure. Kidney multiphase imaging with a spectral photon-counting CT using dual contrast imaging.
Acquisition at 20 seconds after injection of a gadolinium contrast agent, and 60 seconds after injection of an iodine contrast agent.

Iodine images representation of the renal perfusion

A

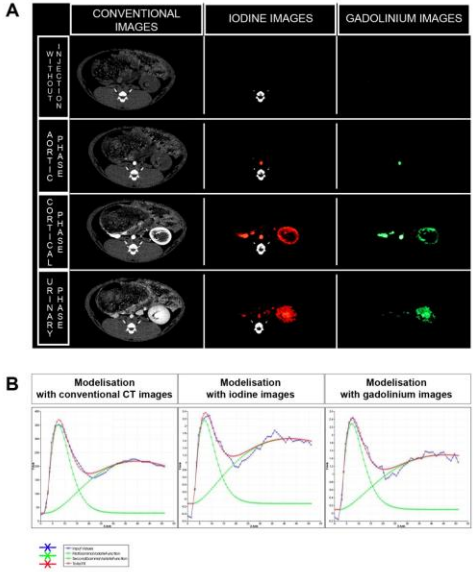


SPCCT provided high spatial resolution conventional HU, specific gadolinium K-edge and iodine material decomposition images (Fig A).

SPCCT images allowed modelisation of kidney perfusion using a validated gamma variate model (Fig B)

SPCCT allows dynamic acquisition (Fig C)

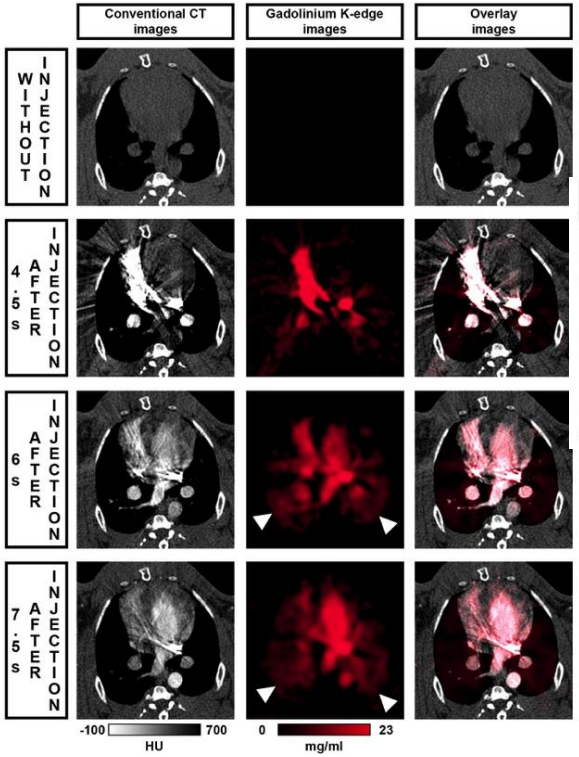
B



C

K-EDGE SPCCT ANGIOGRAPHY WITH A NEW HIGHLY CONCENTRATED GADOLINIUM CONTRAST AGENT

A highly concentrated gadolinium contrast agent allows K-edge imaging



A.Figure: Representative conventional HU images (left), gadolinium specific K-edge images (center), and overlay (right) acquired at the level of the heart in a NZW rabbit, demonstrating perfusion of the lungs (head arrow) and myocardium.

B.Table: Peak gadolinium concentrations in the regions of interest

Organs	Time to peak [s]	Mean [mg/mL]	SD [mg/mL]
Right ventricle	3.5	25.8	2.1
Pulmonary artery	3.5	11.6	1.2
Lung	5.5	2.3	1.1
Pulmonary vein	5.5	9.8	1.4
Left ventricule	7.5	10.2	0.3
Aorta	7.5	6.4	0.8
Myocardium	7.5	2.0	0.75

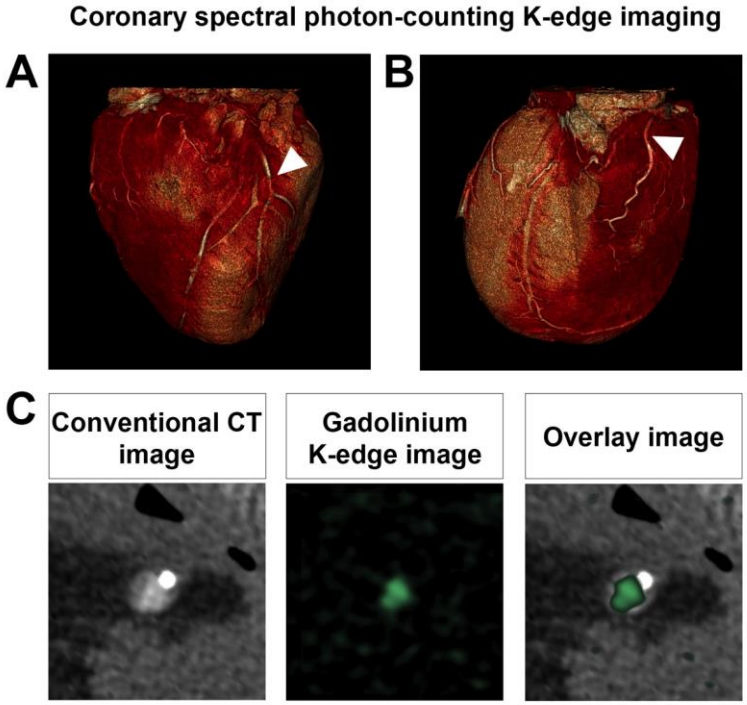
Clinical relevance :

Gadoteridol presents the potential of K-edge perfusion imaging using a spectral photon-counting CT

K-edge imaging drastically increases the contrast to noise ratio

Implications for patient care: Highly concentrated gadoteridol may be used a clinically compatible volumes to perform highly specific quantitative perfusion imaging with Spectral Photon-Counting CT (SPCCT).

CORONARY IMAGING WITH MULTIENERGY SPCCT K-EDGE IMAGING



SPCCT allowed a better depiction of coronary lumen using K-edge imaging with a gadolinated contrast agent.

SPCCT *CONCLUSIONS*

- In-vivo spectral photon counting CT acquisition on a "clinical" sized system with multi contrast multiphase K-edge Imaging
- Need for further improvement (H2020)
- In:
  - Detector performance
  - Reconstruction techniques and
  - denoising
  - Contrast agents developments

H2020 SPCCT NEXT PHASE:

Ex-vivo, pre-clinical (hours, 100 µA)

In-vivo pre-clinical (100 mA)

Clinical (sub-seconds, 600mA)

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