Přehled technických novinek z pohledu společnosti Philips

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Application CT &MRI CEE

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November 2020, Kladno, Czech Republic

Přehled bodů

- Spektrální CT– cesta k innovaci + trochu teorie
- Klinicko- technické benefity spektrálního CT
- Klinické příklady aplikací spektrálního CT dle anatomie
- Jaké jsou možnosti dalších inovací

- Postprocessing /ISP
- AI v CT oblasti

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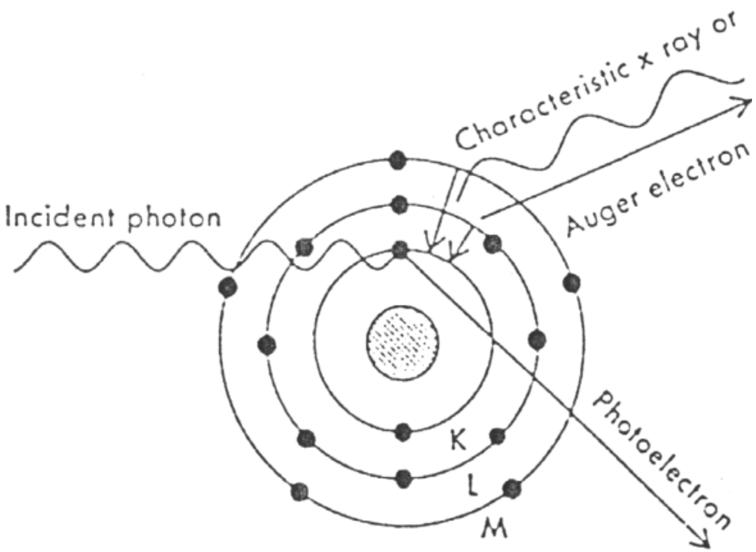
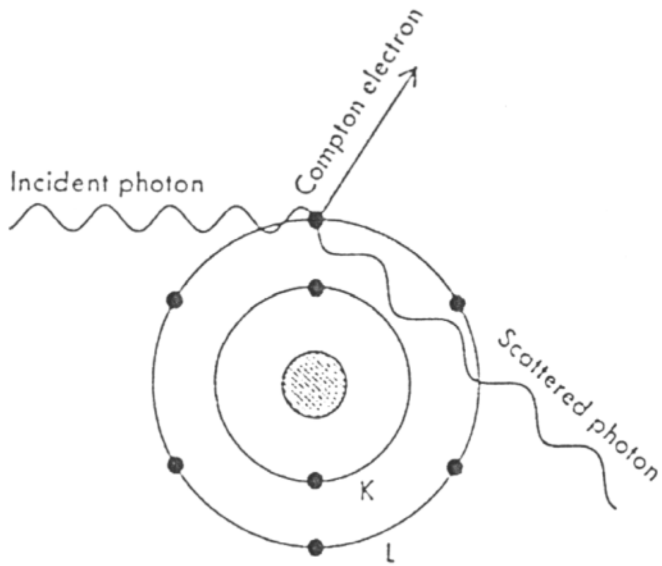
X-Ray Attenuation

- At CT energies, linear attenuation μ is the result of 2 microscopic interactions between X-ray photons and tissue:
  - Photoelectric absorption (effect): μ_p
  - Compton scattering: μ_c



Photoelectric absorption



Compton scattering

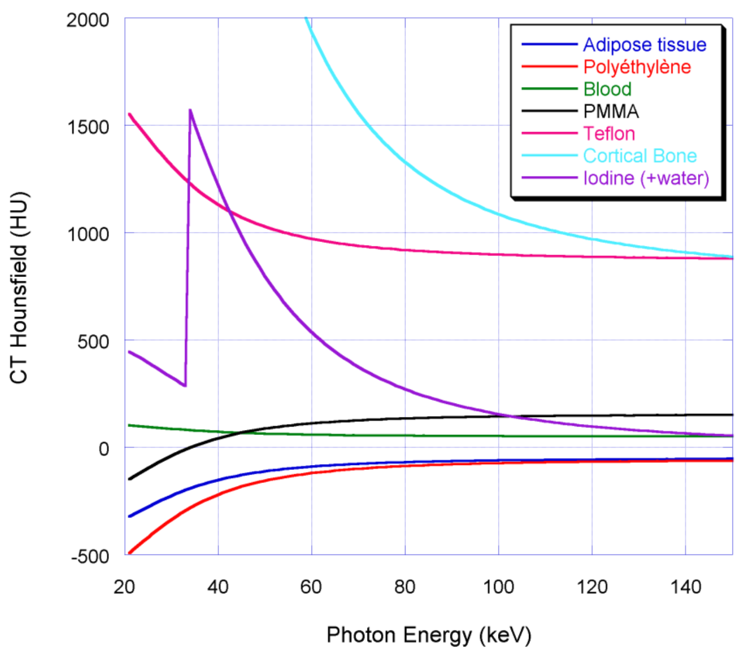
$$\mu = \mu_p + \mu_c$$

X-Ray Attenuation

- X-ray attenuation depends on the incident X-ray energy and on the effective atomic number of the traversed tissue

- Different tissues exhibit different combinations of photoelectric absorption and Compton scattering

$$\mu(E) = \mu_P(E) + \mu_c(E) = \alpha_P f_P(E) + \alpha_c f_c(E)$$



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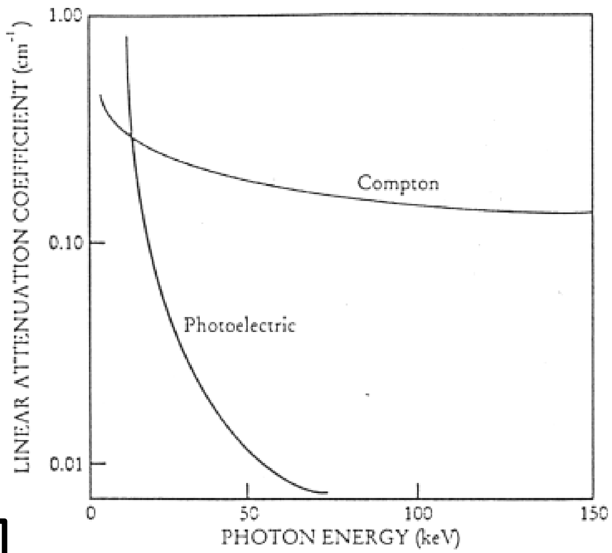
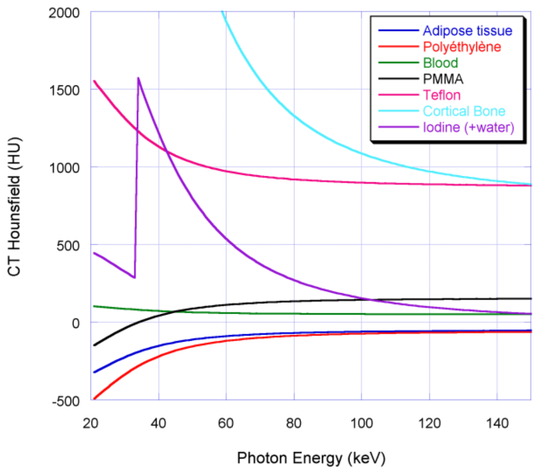


(α_p, α_c) : characteristic of material/tissue

$$\begin{cases} \alpha_P \propto \rho Z_{eff}^{3.8} \\ \alpha_c \propto \rho Z_{eff} \end{cases}$$, ρ *is the mass density*

(f_p, f_c): independent of material, only dependent on energy *

$$\begin{cases} f_P(E) \propto 1/E^{3.2} \\ f_c(E) \end{cases}$$ *is the Klein-Nishina function: weakly dependent on energy E*



* Alvarez R.E. and Macovski A., Energy-Selective Reconstructions in X-ray Computerized Tomography, Phys.Med.Biol. 1976, 21(5), 733-744.

X-Ray Attenuation

- X-ray attenuation depends on the incident X-ray energy and on the effective atomic number of the traversed tissue

- The atomic number Z is the number of protons found in the nucleus of an atom. Example: Hydrogen Z=1, Oxygen Z=8

- The effective atomic number Z_{eff} is a term similar to the atomic number Z but is used for compounds

$$Z_{eff} = \sqrt[2.94]{f_1(Z_1)^{2.94} + f_2(Z_2)^{2.94} + f_3(Z_3)^{2.94} + \ldots}$$

Where f_n is the fraction of the total number of electrons associated with each elements and Z_n is the atomic number of each element

e.g. water $H_2O \rightarrow Z_{eff} = \sqrt[2.94]{0.2(1)^{2.94} + 0.8(8)^{2.94}} = 7.42$

	Z_{eff}
Gadolinium	64.0
Iodine	53.0
Calcium	20.0
Cortical Bone	13.23
Water	7.42
PMMA	6.52
Fat	5.92

Dual-Energy Acquisition

$$\begin{cases} \mu(E_L) = \alpha_P f_P(E_L) + \alpha_c f_c(E_L) \\ \mu(E_H) = \alpha_P f_P(E_H) + \alpha_c f_c(E_H) \end{cases}$$

⇓

Solve for α_P and α_C

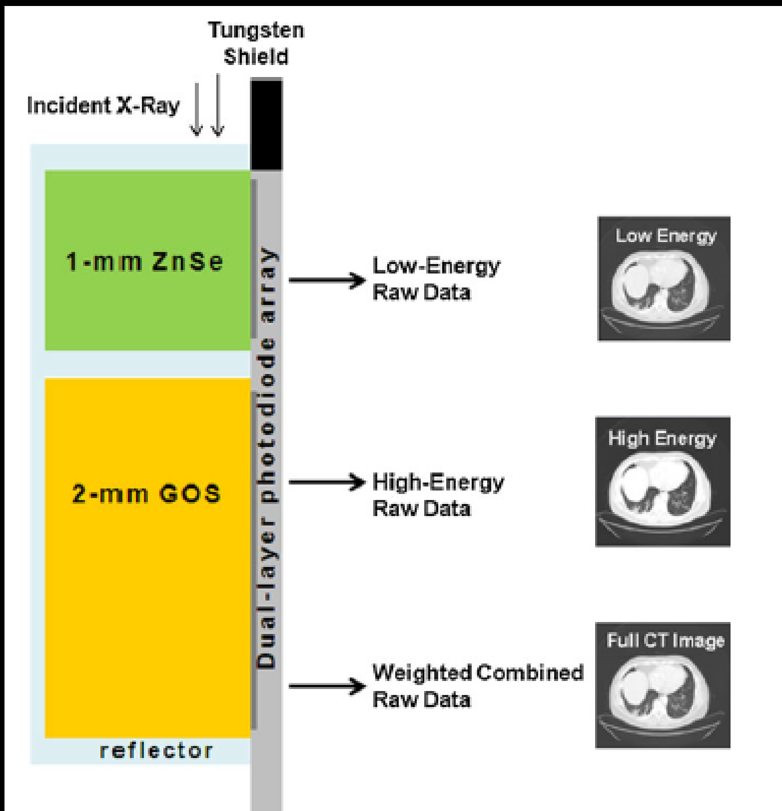
Different materials/tissues are characterized by their unique pair of attenuation parameters (α_p, α_c)

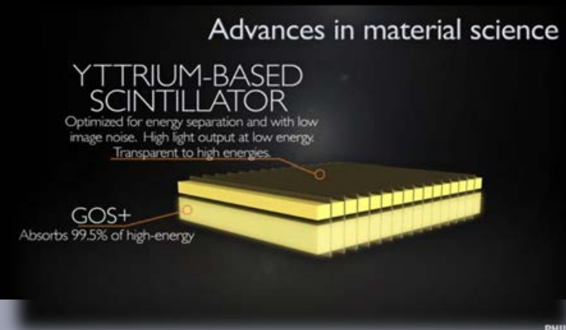
Different materials/tissues that may lay out same HU values in single acquisition CT can now by "characterized" using the dual-energy CT by measuring (α_p, α_c)

Polychromatic nature of the beam can be corrected in the calculation of α_P and α_c if the x-ray spectrum is known *

* Alvarez R.E. and Macovski A., Energy-Selective Reconstructions in X-ray Computerized Tomography, Phys.Med.Biol. 1976, 21(5), 733-744.

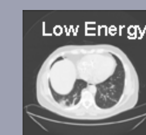
The dual layer Spectral Detector, Principle and Operation





~50%

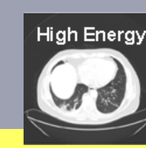
→ Low Energy Raw data → **E1 image**



+

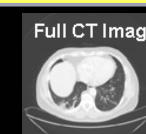
~50%

→ High Energy Raw data → **E2 image**



=

Weighted combined Raw data → CT image



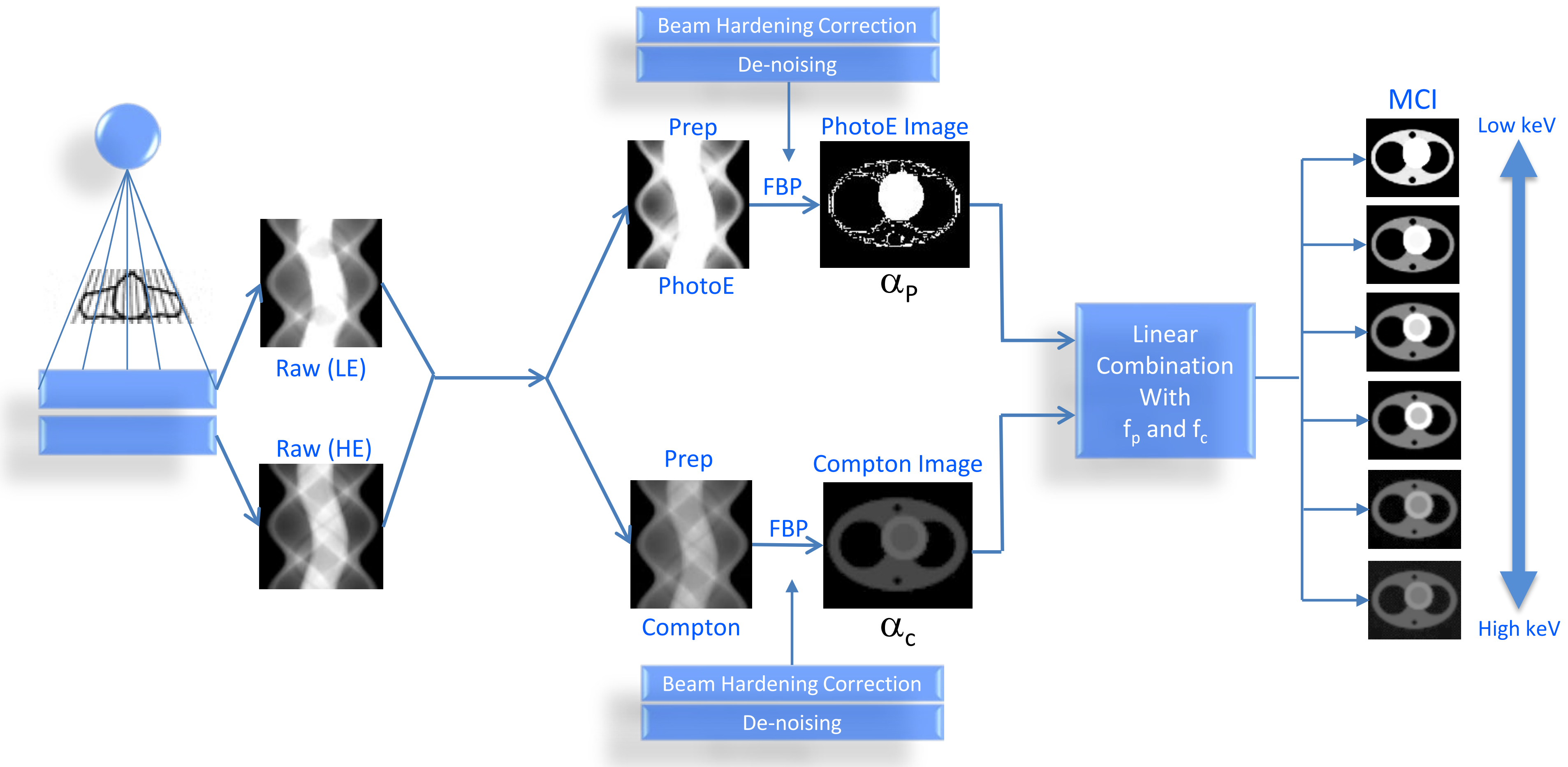
1. For optimal performance the effective atomic number of the top scintillator is small without sacrificing light output .
2. Top Scintillator thickness has been optimized for best energy separation and low-energy image noise
3. Bottom scintillator is GOS, the thickness of which set to absorb 99.5% of the High-Energy spectrum (note that light collection is sideways)

Ami Altman & Raz Carmi Philips Healthcare

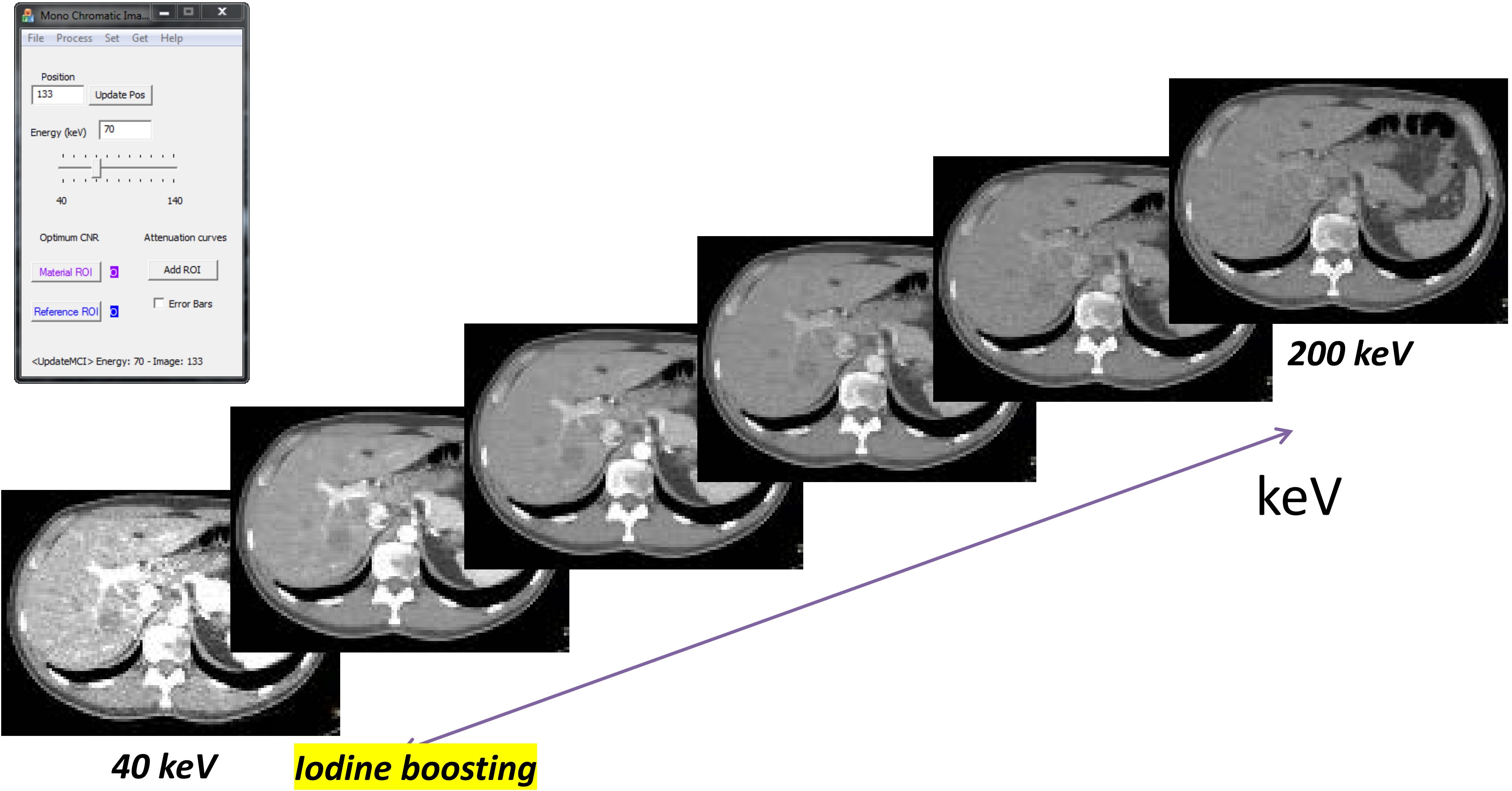
Photoelectric - Compton Decomposition

Virtual Mono Energetic Imaging

$$\mu(E) = \mu_P(E) + \mu_c(E) = \alpha_P f_P(E) + \alpha_c f_c(E)$$



Photoelectric - Compton Decomposition
Virtual Mono Energetic Imaging

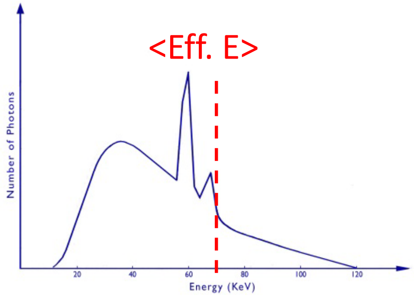


Photoelectric - Compton Decomposition
Virtual Mono Energetic Imaging

Spectrally Enhanced Routine CT Imaging

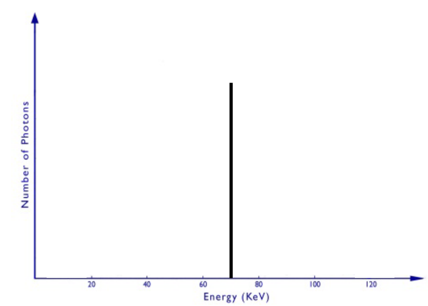
Conventional CT Image

Conventional 120 kV CT Image



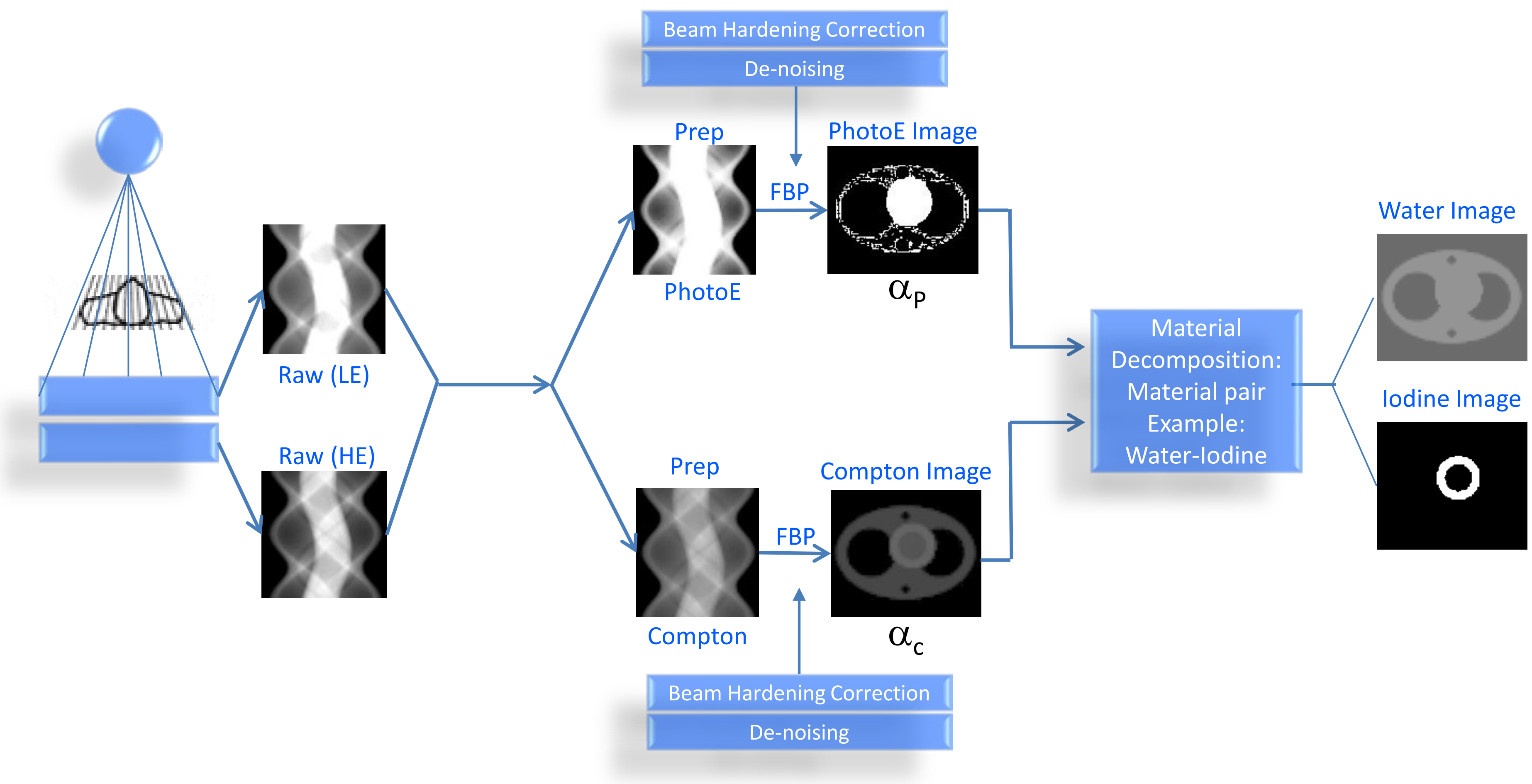
kVp *Equivalent* Mono-Energy Image

Virtual Mono-Energy CT Image

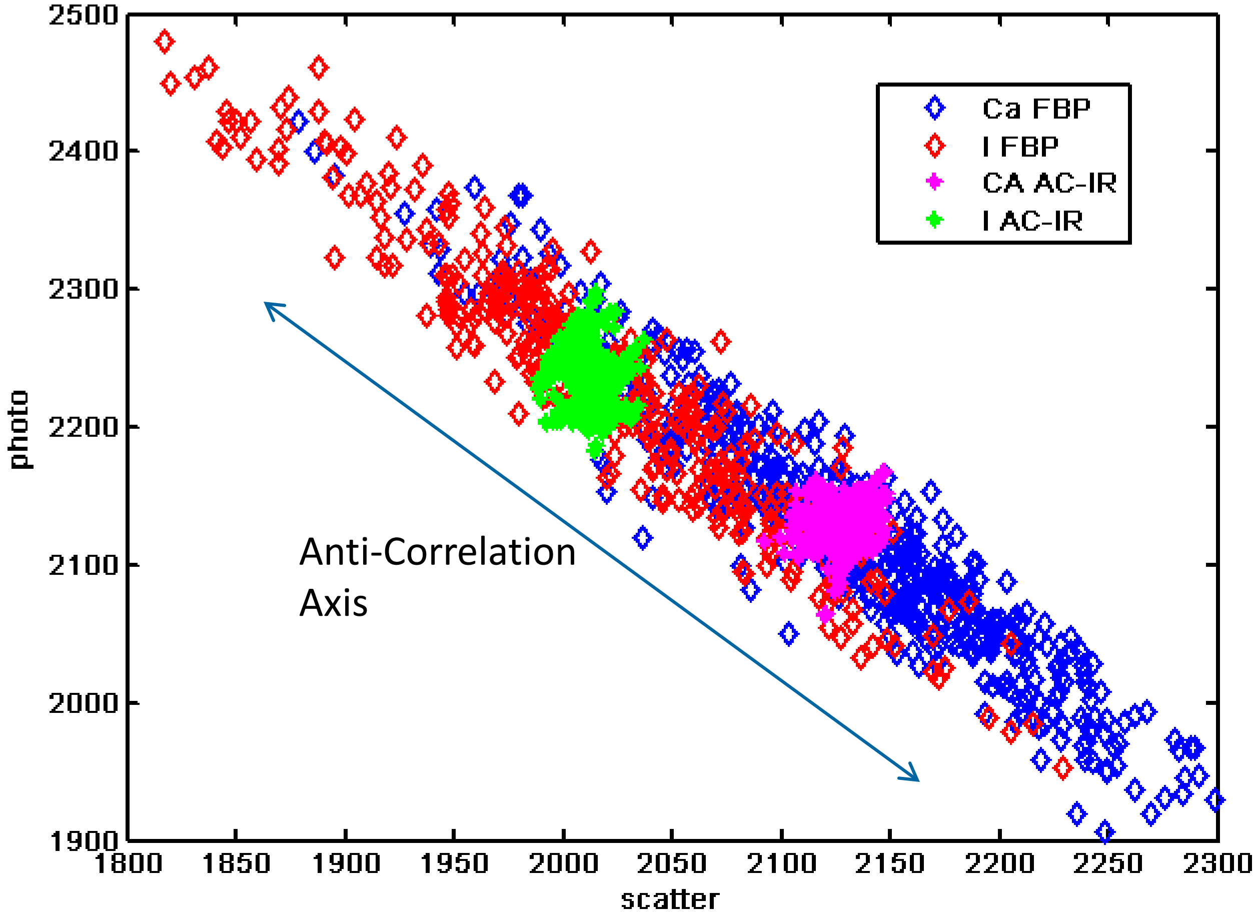


Photoelectric - Compton Decomposition

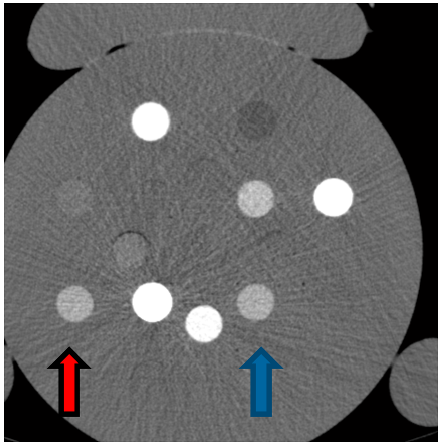
Material Specific Imaging

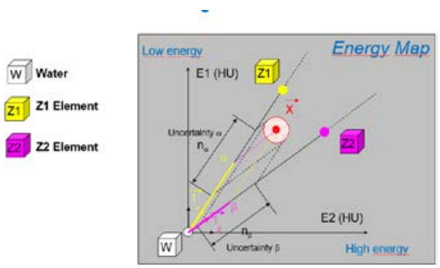


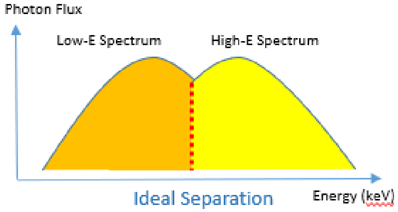
Spectral Separation

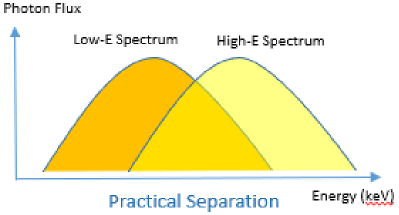


7.5 mg/ml iodine, 50 mg/ml calcium

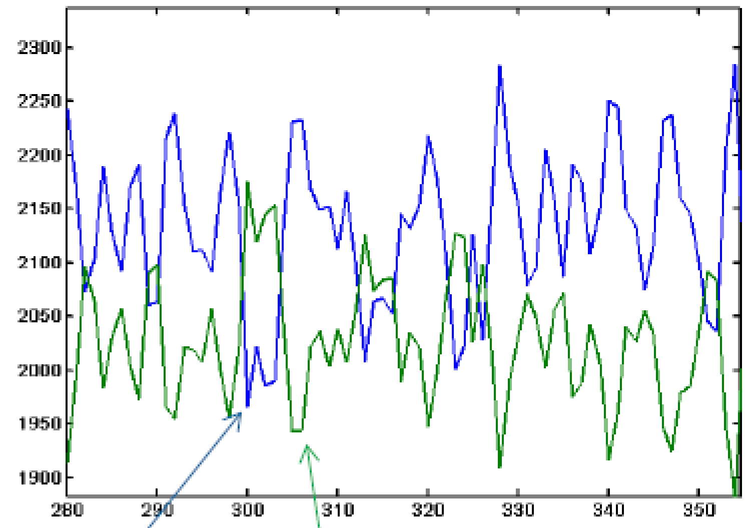








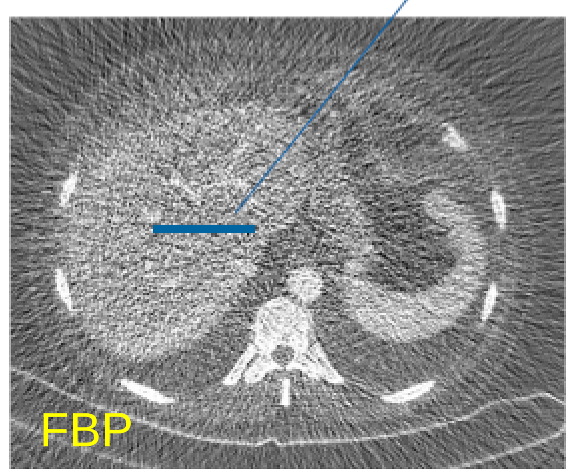
Anti-Correlated Noise



- All decomposition functions amplify the noise in the basis coefficient images.
- This noise has the special property of being “anti-correlated” between the two basis images.

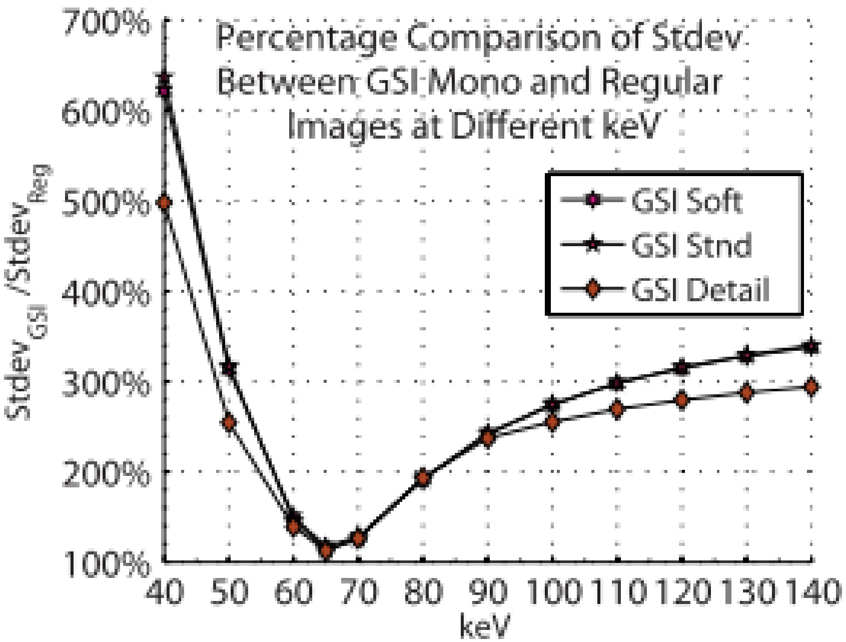
Conventional

$\alpha_p(x,y)$

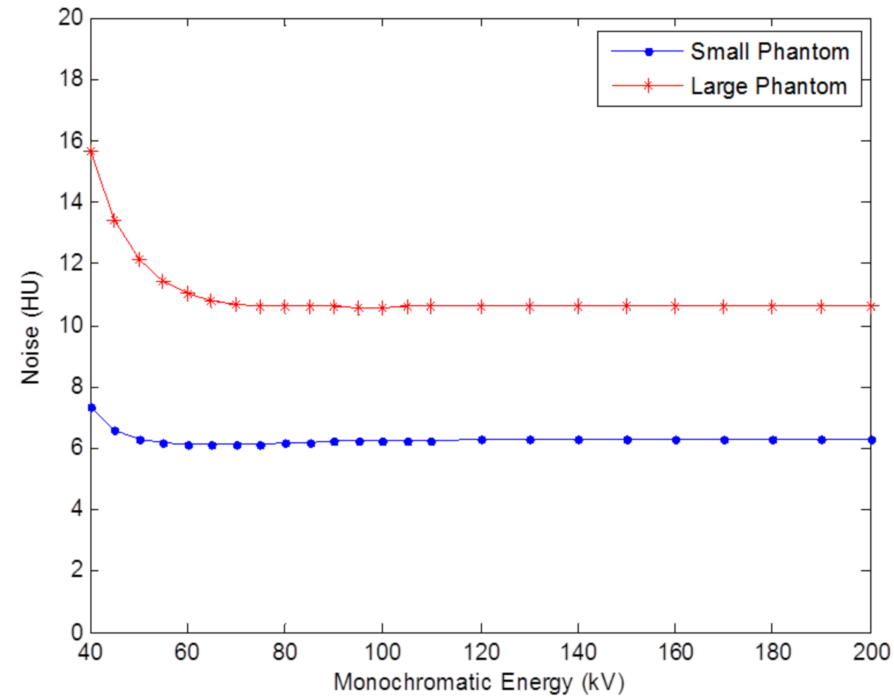


$\alpha_c(x,y)$

Mono-Chromatic Images



AC-IR Images



** Zhang, et. al., *Medical Physics*, 38(3), 2011

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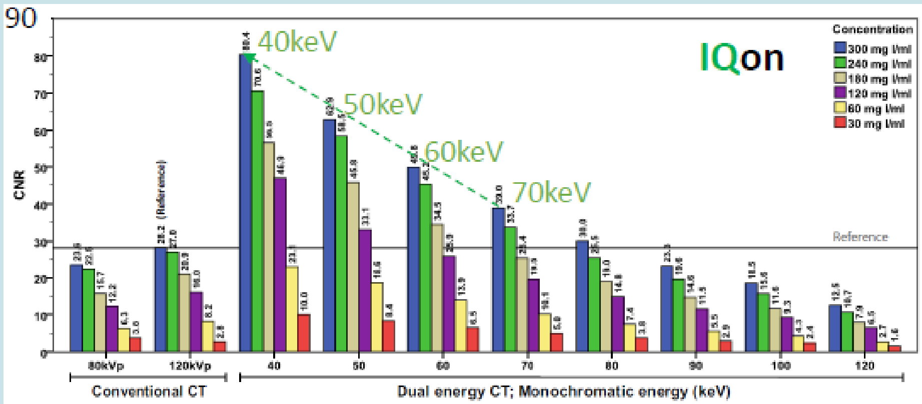
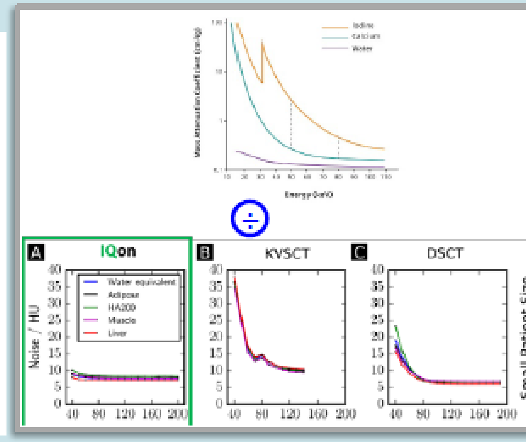
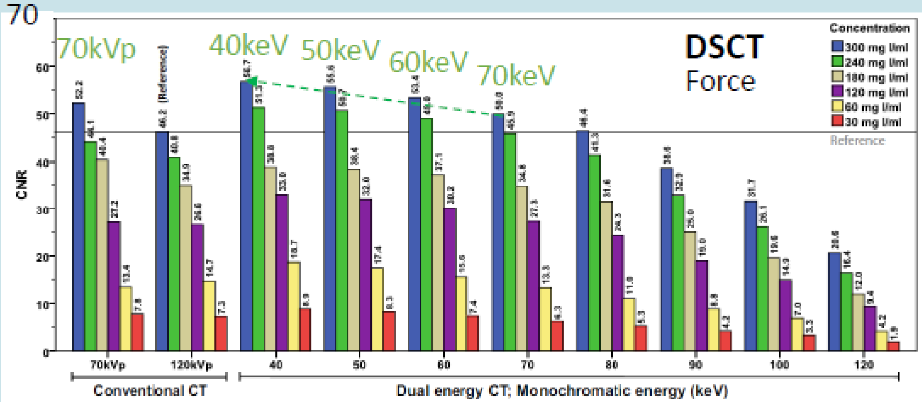
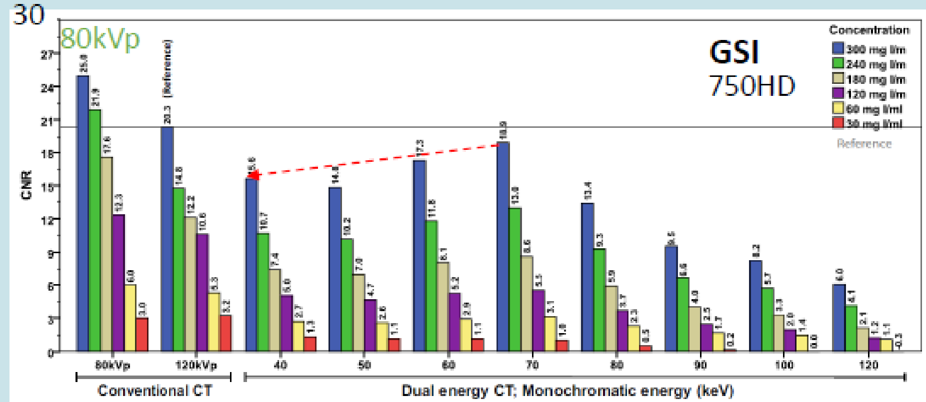
… Virtual monoenergic images - CNR

IQon low noise MonoE images translate the benefit of strong contrast increase at low energy in strong CNR increase.









Contrast agent concentration optimization in CTA using low tube voltage and dual-energy CT in multiple vendors: a phantom study. R. van Hamersvelt et al., The International Journal of Cardiovascular Imaging, 2018. https://doi.org/10.1007/s10554-018-1329-x

Results from case studies are not predictive of results in other cases. Results in other cases may vary.

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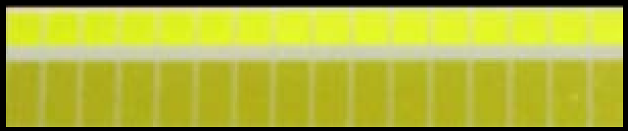
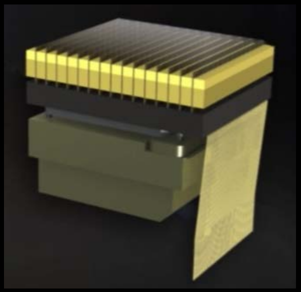
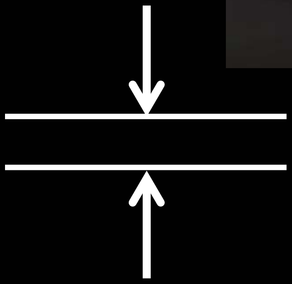
1

Simultaneous Spectral Detection





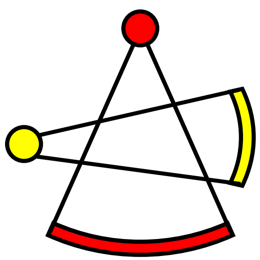


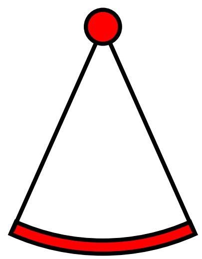
$\sim 3.0 \times 10^{-9}$ s

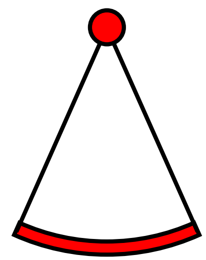
- Slower, source-based dual-energy methods:
  - May have temporal spectral sampling differences of up **to 70 ms**, or more
  - May result in vascular movement of up to 4 mm & quantification errors
- Simultaneous detection
  - Temporal spectral sampling differences reduced to effectively zero
  - No rotation-time limitations (0.27 s)

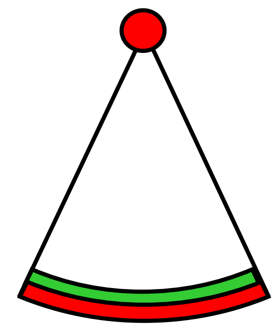
IQon Spectral CT – comparison

Technology Paths to Dual-Energy Acquisition









Dual Source

Spectral mode:
needs to be pre-selected
2 tubes (80 0r 100/140 kVp
70/150kVp)

Limited FOV
Limited temporal resolution
BARIATRIC limited

kV/filter Switch

Spectral mode:
needs to be pre-selected
Fast kV switching:
80/140kVp, similar to
Filter changing approach.

Limited resolution
Tube lasting
BARIATRIC limited

Dual Spin

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

Slow temporal resolution
High advanced registration
Processes needed
No contrast studies

Detection Based

SPECTRAL ALWAYS ON

Scan @120 kVp
Tube mA modulation
Dose Neutral

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2

Spectral information for every patient with no prior selection before scanning

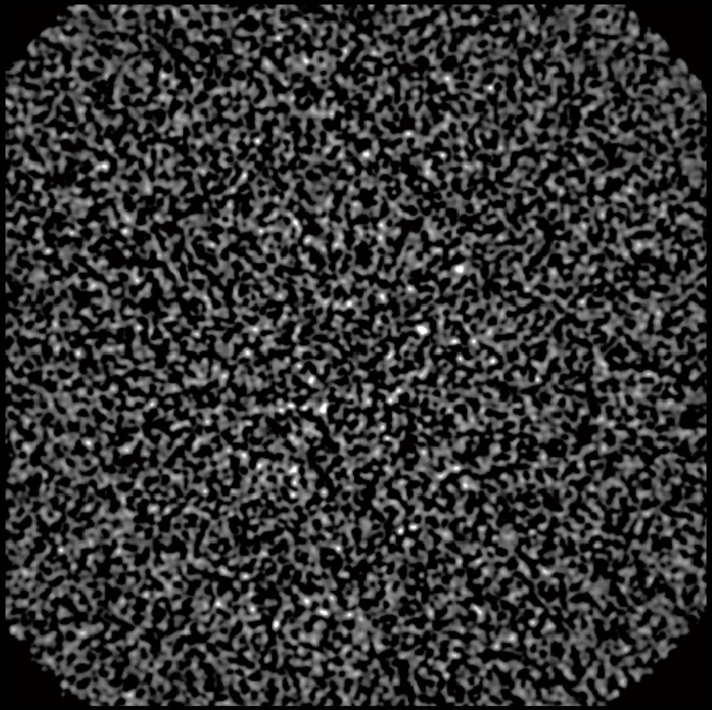
Clinical Impact of Retrospective SDCT Analysis

- Spectral information has affected diagnosis in 44% of cases
- Multi-Energy CT was *not indicated* a priori for 31% of cases
- Retrospective Spectral Analysis aided diagnosis in those 31%

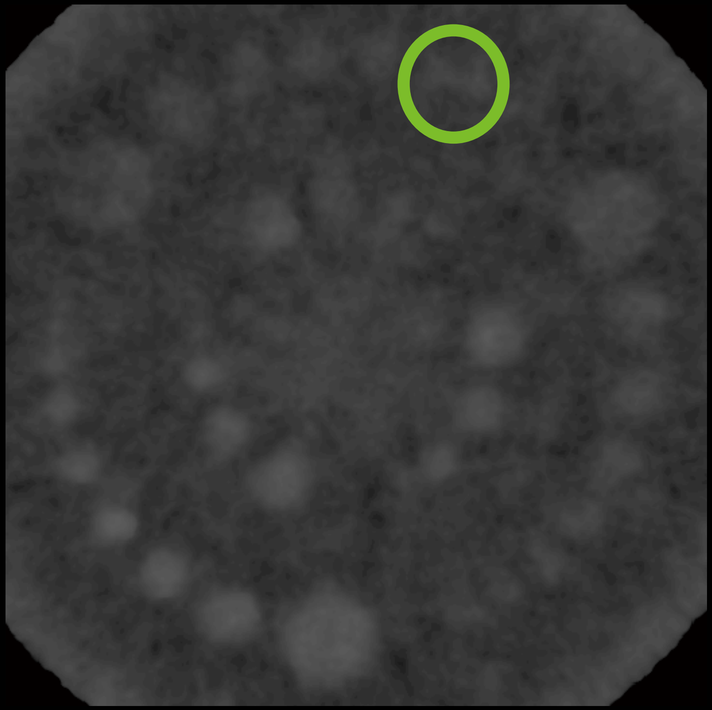
Embedding of model-based IR – the only one working in triggered scanning – extra low dose

3

1 mm Slice Thickness, 2mm, 0.3% @ 10.4 mGy $CTDI_{vol}$



Standard Reconstruction
(FBP)



IMR

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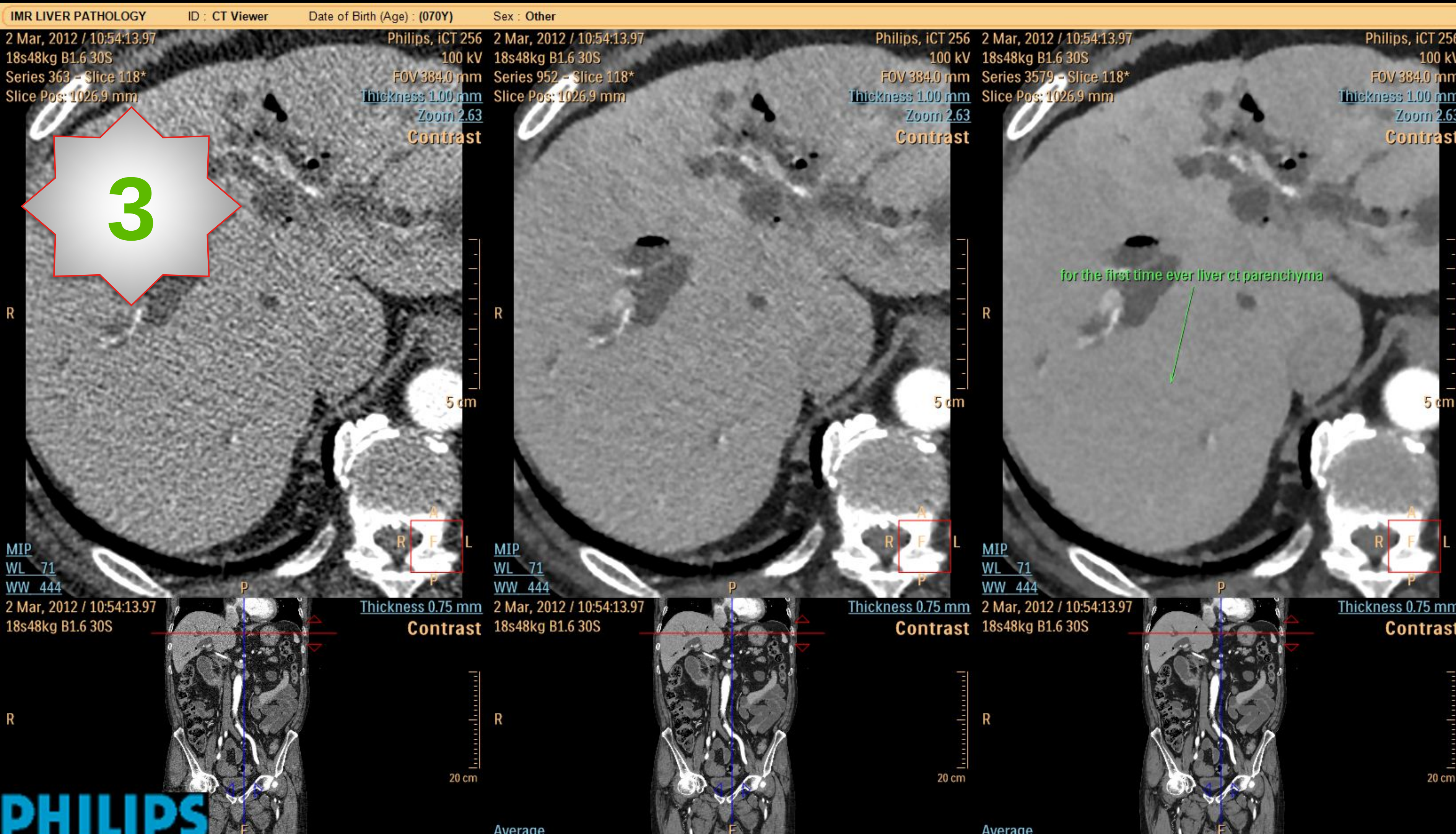
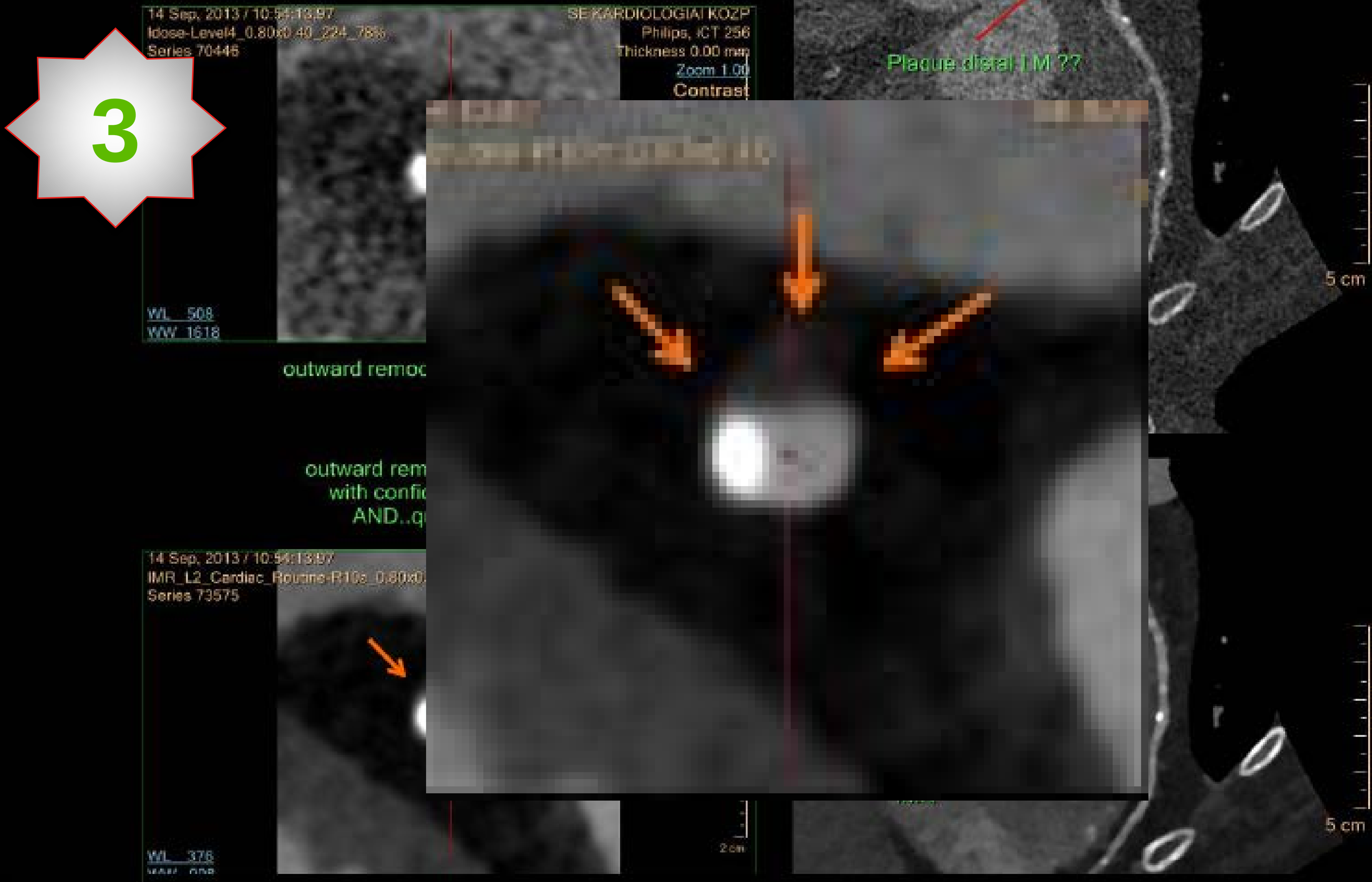


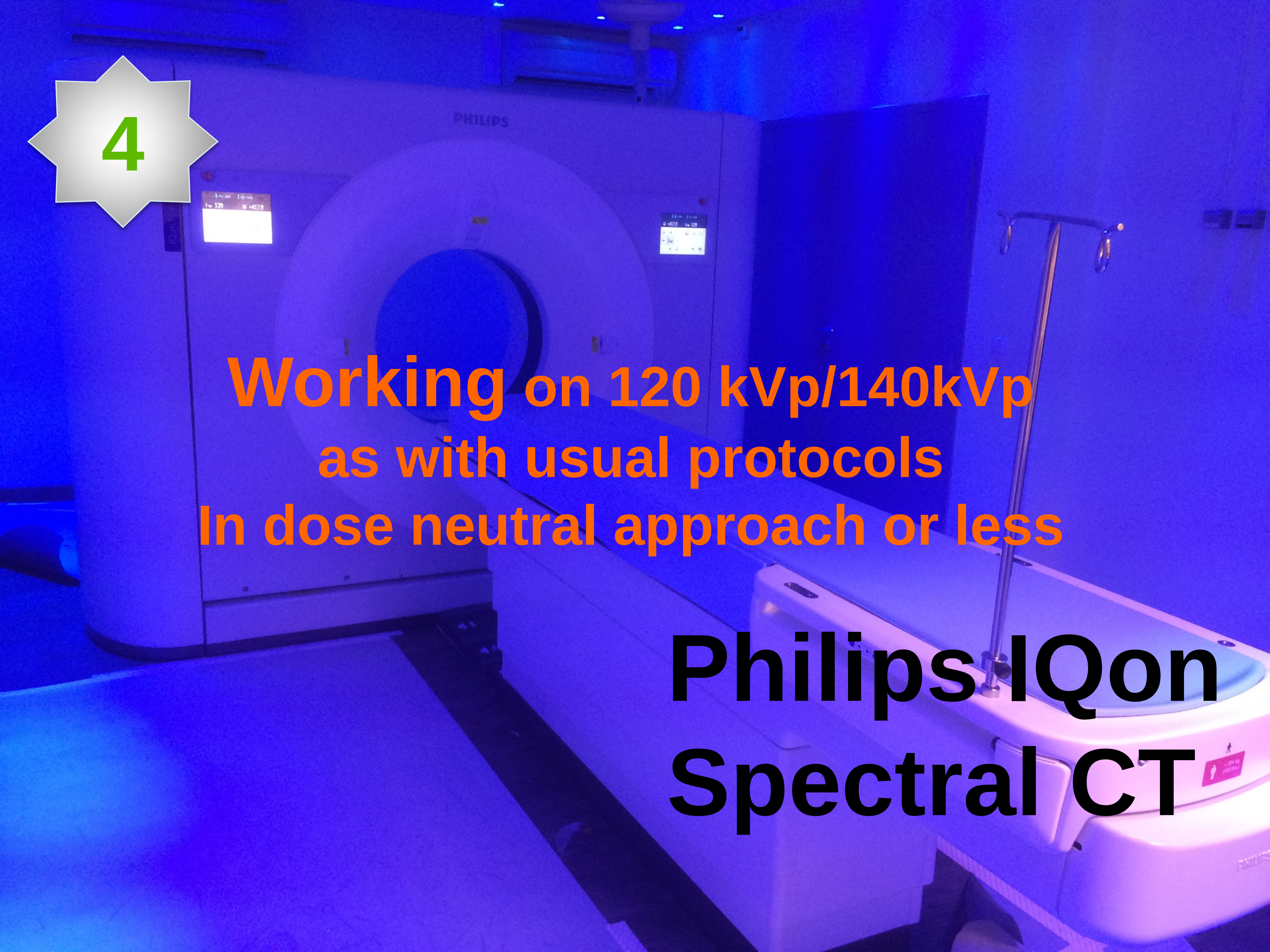
Pancreas tu – first ever real liver parenchyma

Courtesy: Amahusa Med.Cent, USA

S&S in morbidly obese female
Max tube settings 120kV, 300mAs



IMR is superior to iDose in NC Plaque detection / delineation.


4
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Working on 120 kVp/140kVp
as with usual protocols
In dose neutral approach or less
Philips IQon
Spectral CT

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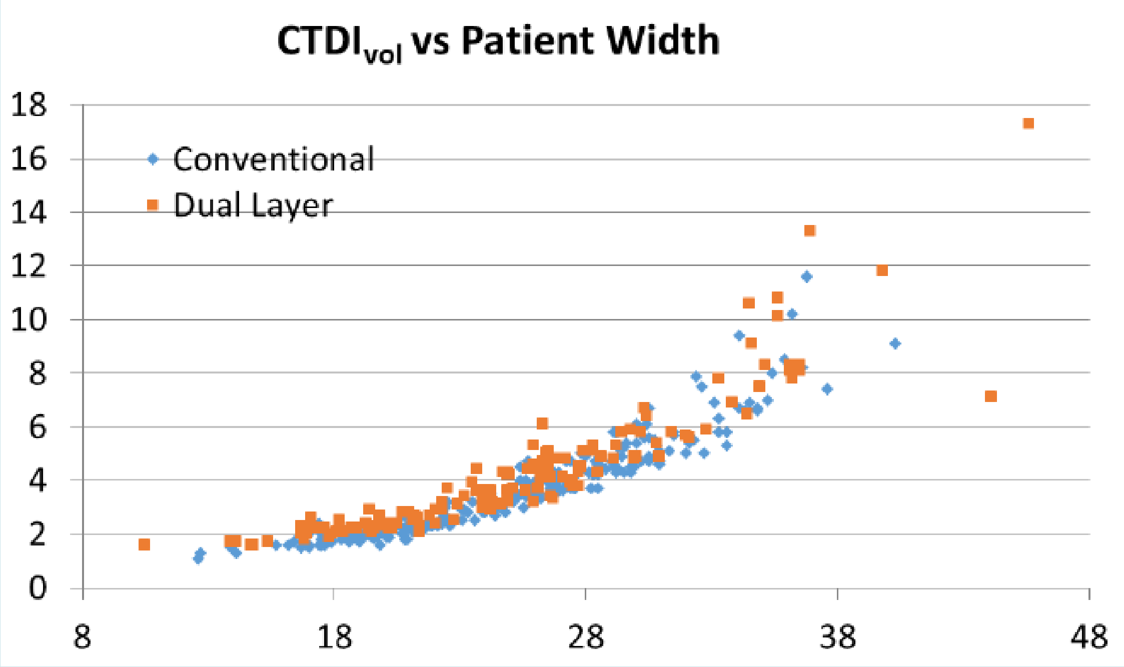
IQon scans are dose neutral

Dose Comparison Study

- scanned on conventional scanner (iCT 256) versus IQon.
- Identical protocols on two scanners, except weight based kVp adjustment and 80 mm collimation used on iCT256.
- ***Measured dose differences between 18.3% and -22.0%***



Phantom Studies Show Dose and Image Quality Equity in Pediatric Clinical Body and Brain CT Protocols for Multi-Energy Spectral CT (MECT) and 256 row Multi-Detector CT (MDCT), Dianna M. E. Bardo, MD, Richard N. Southard, MD, Robyn Augustyn, RT (CT), Marrit Thorkelson, RT (MR), Nicholas Rubert, PhD., Presented at the 60th Annual Meeting of the AAPM

Courtesy of: Phoenix Children's Hospital, Phoenix, Arizona, USA

Results from case studies are not predictive of results in other cases. Results in other cases may vary.

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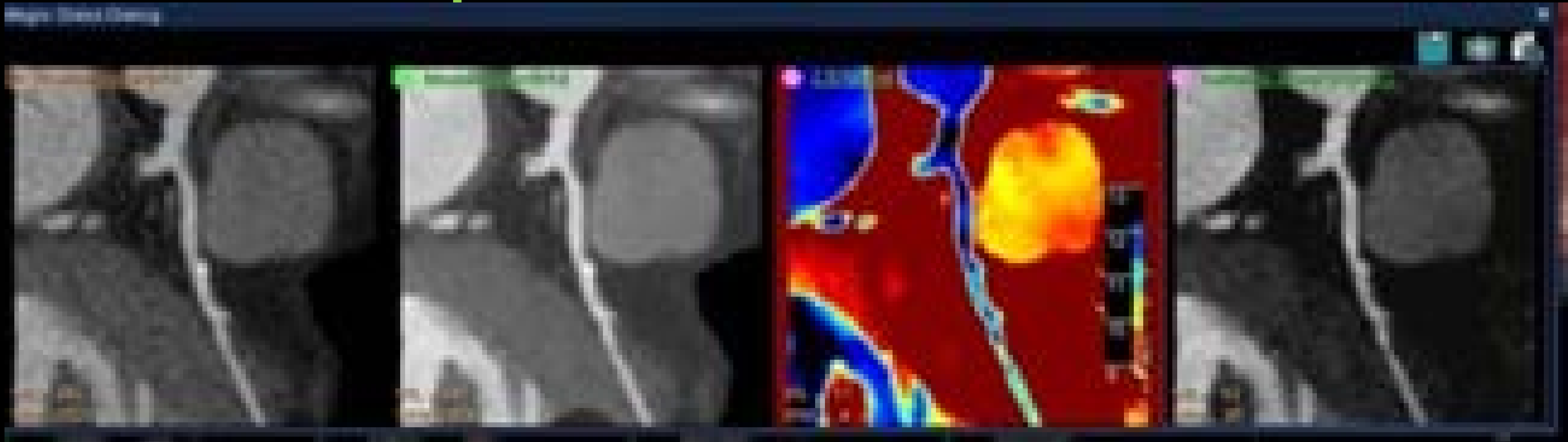
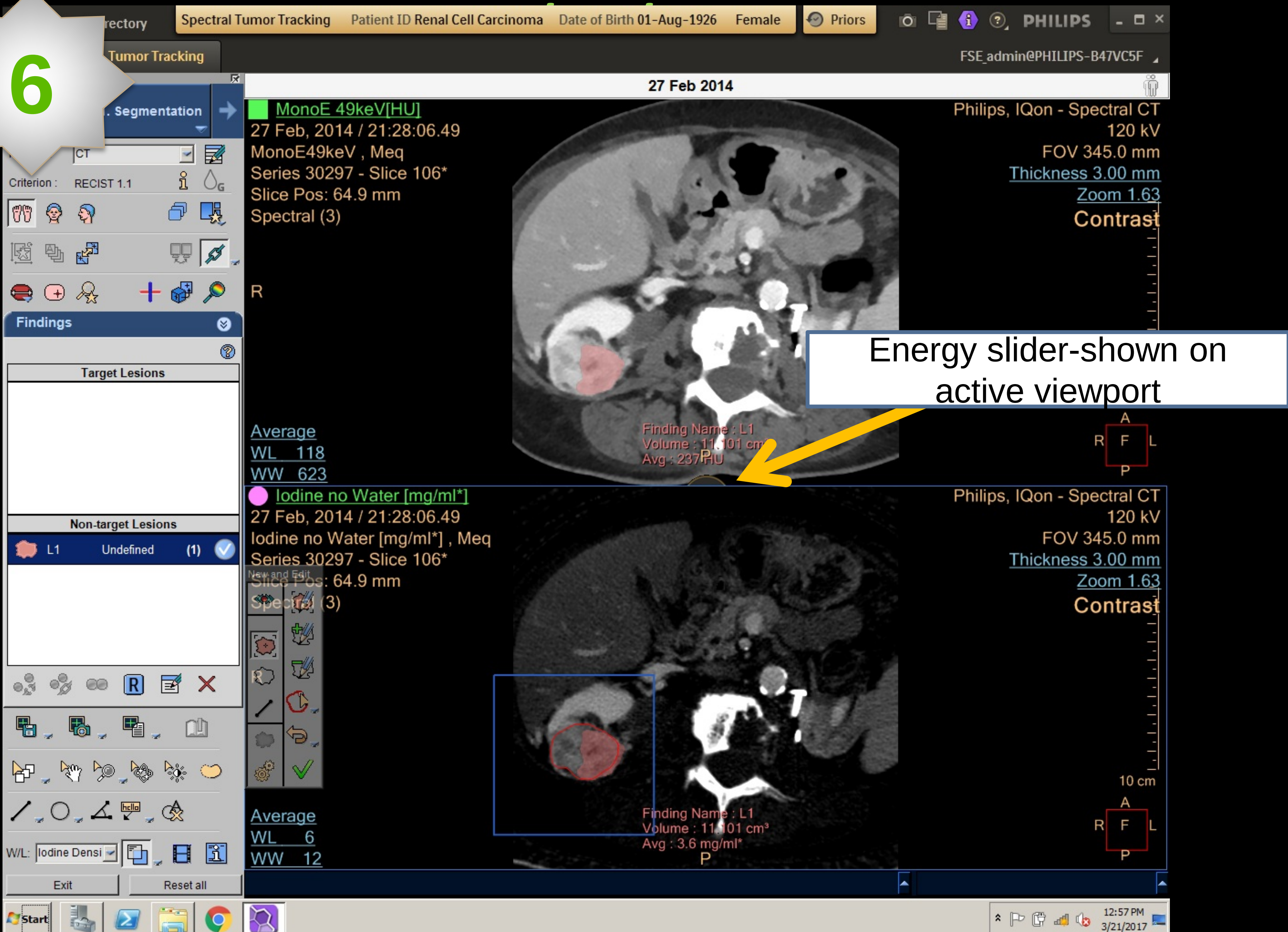
Smalest Isotropical Spectral Voxel

- Full FOV spectral CT
- No time space in acquiring of voxels
- No spatial resolution compromise in either voxel axis- isotropic



Spectral post processing+ storage- same type of SW

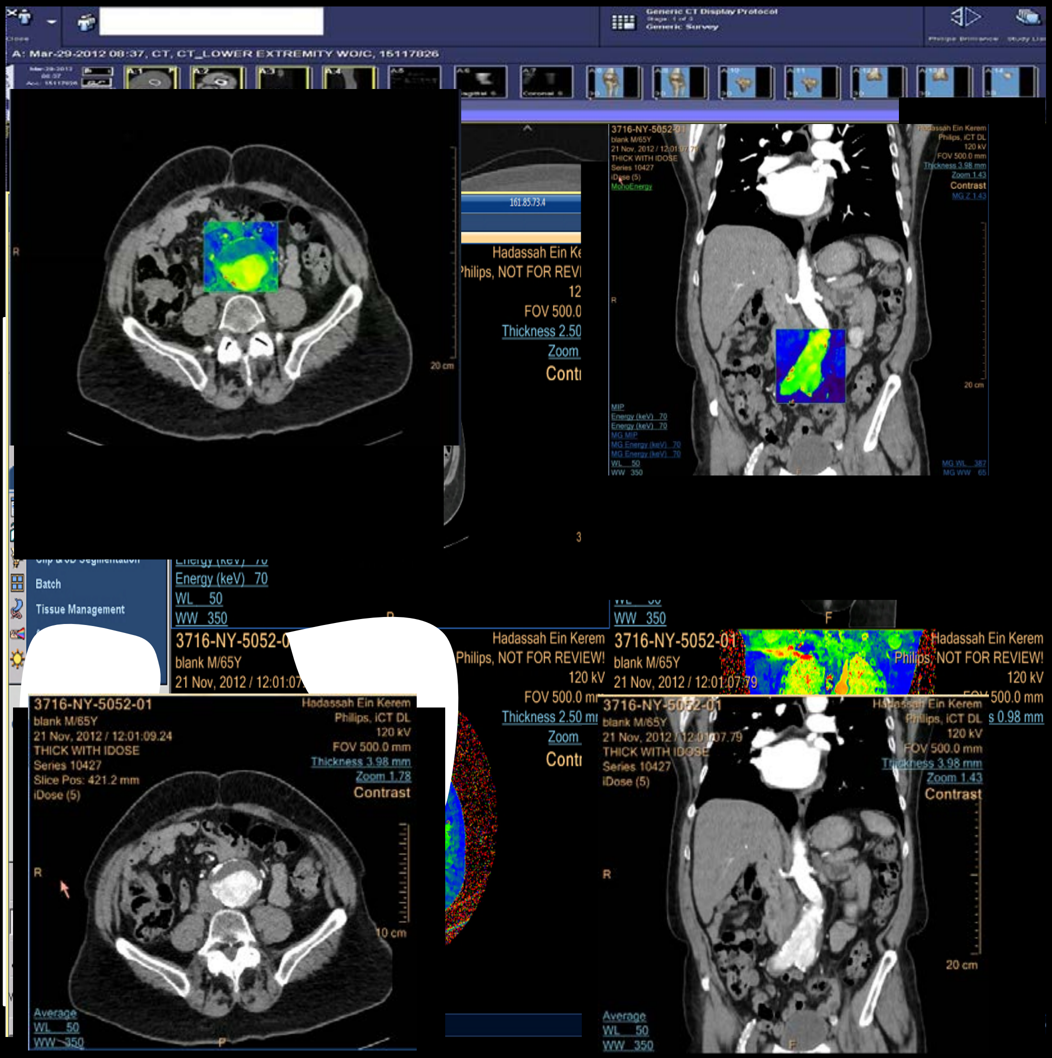
6



7

Spectral storage for every patient- SBI

- Spectral information is compatible to DICOM standard and could be stored on PACS .
- Additional tool for quick spectral analysis on PACS -Magic Glass
- Retrospektive analysis always there and future



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Spectral Results

Spectral results can be roughly divided into 2 groups: **HU based** and **non-HU based**

HU Based Spectral Results

Label Name	Unit
MonoE75 *(75 is an example of the keV value)*	HU
MonoE75 (120kVp) *(120 is an example of the kVp value)*	HU
Contrast-Enh. Structure [HU]	HU
Iodine Removed [HU]	HU
VNC [HU]	HU
Uric Acid [HU]	HU
Uric Acid Removed [HU]	HU

Non-HU Based Spectral Results

Label Name	Unit
Z Effective (EAN)	Unit less
Iodine no Water [mg/ml]	mg/ml
Iodine Density [mg/ml]	mg/ml

EAN : Effective Atomic Number

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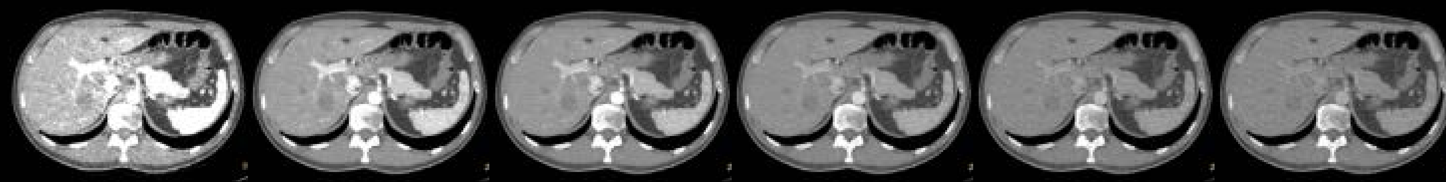
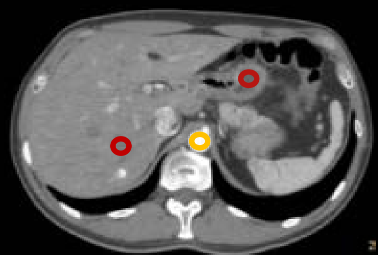
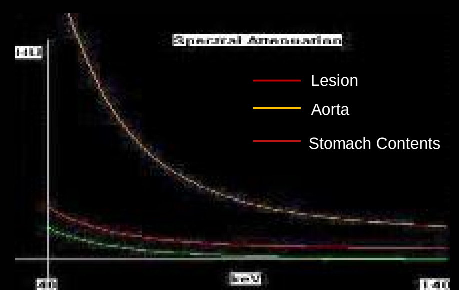
Spectral CT New groups of images types

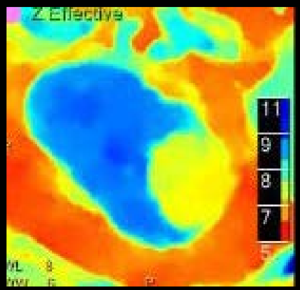
Monochromatic Imaging



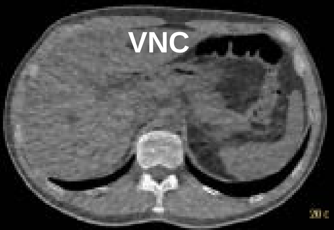
Lesion /Z eff Characterization

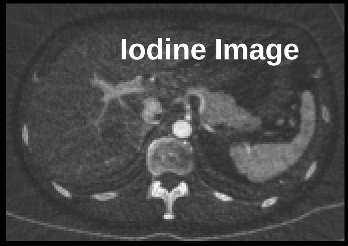


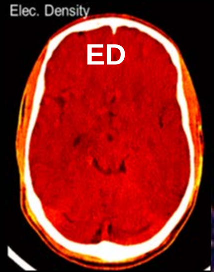


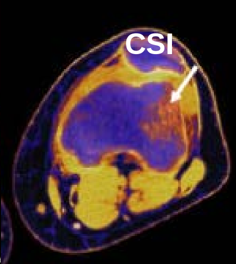


Material Decomposition

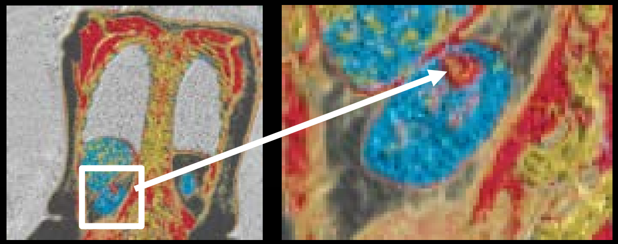


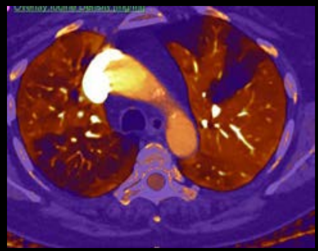


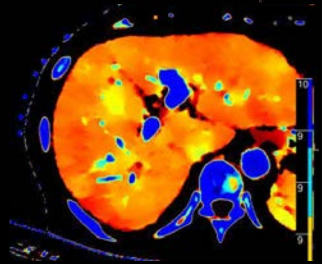




Material Decomposition Overlay images)







Spectral Imaging improves clinical diagnostic

Body Area	Type of pathology	Spectral Benefit
Cardiac& CTA	Plaque	Plaque characterization using EffZ, MonoE
	Perfusion deficit	Increased conspicuity & reduced BH artifact
	Calcium in vessels	Reduced Calcium Blooming
	Large patient & with TRO	No limitation of FOV & full dose modulation tools available
	Missed injection (or reduced iodine dose)	Boost of iodine signal at lower keVs
CT Angiography (Head, Body, Extremities)	Plaque	Plaque characterization using EffZ, MonoE
	Calcium	Reduced Calcium Blooming
	Missed injection (or reduced iodine dose)	Boost of iodine signal at lower keVs
	Compare NC & VNC	Generation of VNC to eliminate NC series
	Vessel assessment	Better bone removal

Spectral Imaging improves quality of clinical diagnostic

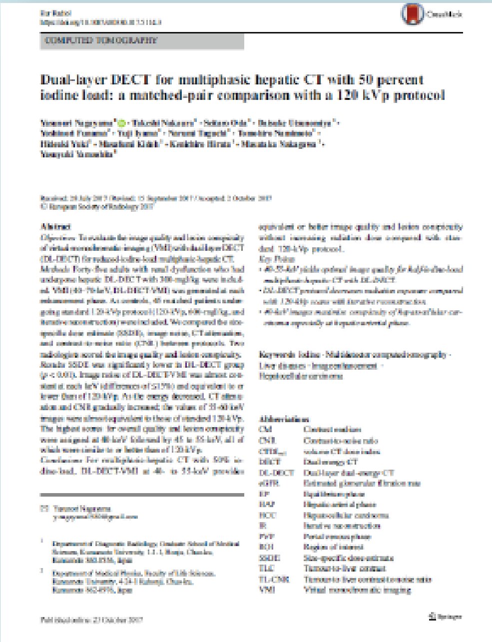
Body Area	Type of pathology	Spectral Benefit
Oncology	Lesion	Increased sensitivity to detection of iodine uptake
	Focal lesions	Increased sensitivity to detection of iodine uptake
	Incidental findings	VNC where NC was not done
	Treatment follow up	Differentiation of hemorrhage vs iodine
	Lung nodule	Differentiation of tumor vs vessels using iodine maps & VNC
	Brain tumor	Differentiation of iodine vs hemorrhage within tumor
	Thyroid nodules	Benign vs malignant
Head	Posterior fossa assessment	Beam hardening reduction in PF region
Metal implants	Metal implants	Artifact reduction
Metabolic	Kidney stones	Detection & characterization
	Gout	Detection & characterization

New spectral CT IQON

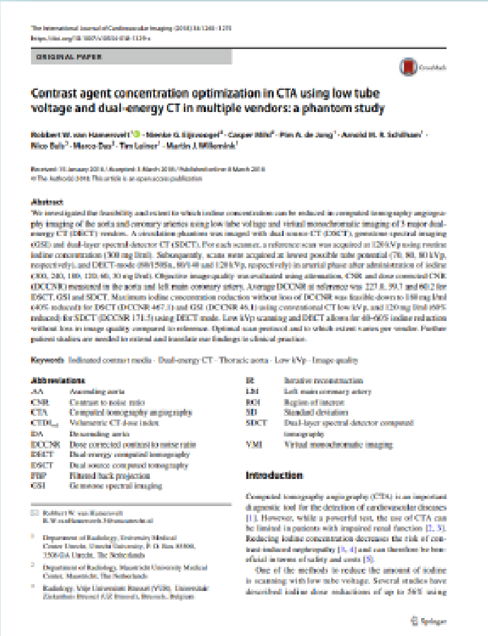
ANGIO

PHILIPS

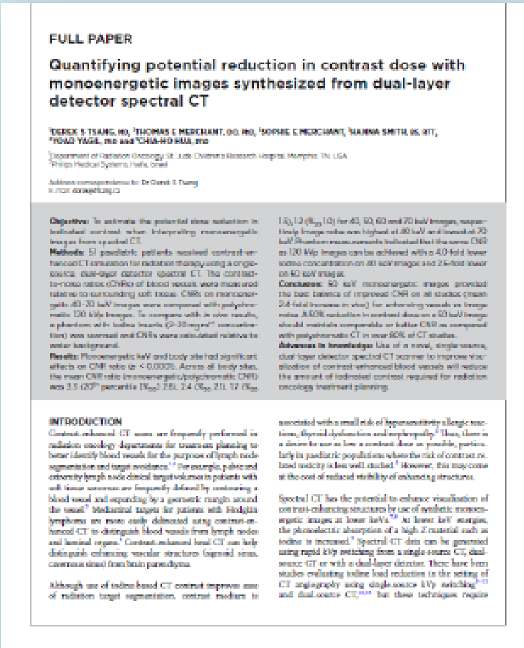
Studies on IQon demonstrate scans with 50% contrast dose


COMPUTED TOMOGRAPHY

Dual-layer DECT for multiphasic hepatic CT with 50 percent iodine load: a matched-pair comparison with a 120 kVp protocol


ORIGINAL PAPER

Contrast agent concentration optimization in CTA using low tube voltage and dual-energy CT in multiple vendors: a phantom study


FULL PAPER

Quantifying potential reduction in contrast dose with monoenergetic images synthesized from dual-layer detector spectral CT

"40-55-keV yields optimal image quality for half-iodine-load multiphasic-hepatic CT with DL-DECT". **Kumamoto University**

Iodine concentration can be reduced by 40-60% (from 300 mg I/ml to 120 mg I/ml). **Utrecht Medical Center**

"A 50% reduction in contrast dose on a 50 keV image should maintain comparable or better CNR as compared with polychromatic CT in over 80% of CT studies." **St. Jude**

Results from case studies are not predictive of results in other cases. Results in other cases may vary.

Mono Chromatic Imaging in Iodine volume reduction

70sec delay

120keV 45keV

Iodine volume reduction

An elderly patient with a history of aortic valve stenosis and renal insufficiency was referred for a pre-TAVI CTA, but was unable to tolerate the full volume of contrast necessary to obtain needed information from conventional CT.

CTDIvol: 14.6mGy
DLP: 657mGy ×cm
Effective Dose: 9.8mSv
*(k=0.015)**

Courtesy of University Hospital, Cleveland

New spectral CT IQON

Improvement of imaging in contrast studies /iodine boosting phenomena/

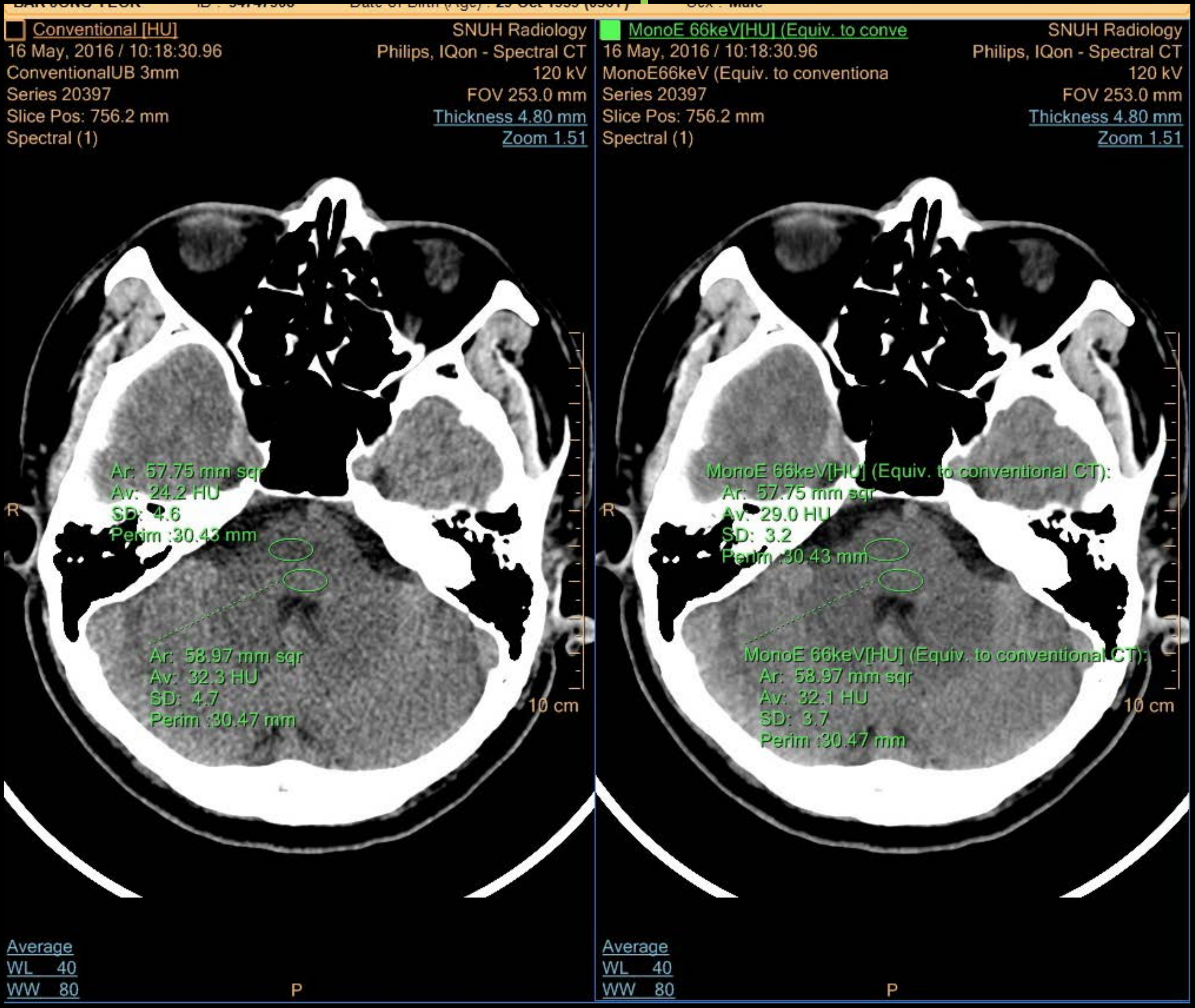
- Contrast improvement in imaging
- Visualization of enhancement even by small amount of contrast
- Missed contrast injection
- Ruptured veins
- Renal dysfunctions in oncological patients

CM dose reduction !

New spectral CT IQON

HLAVA

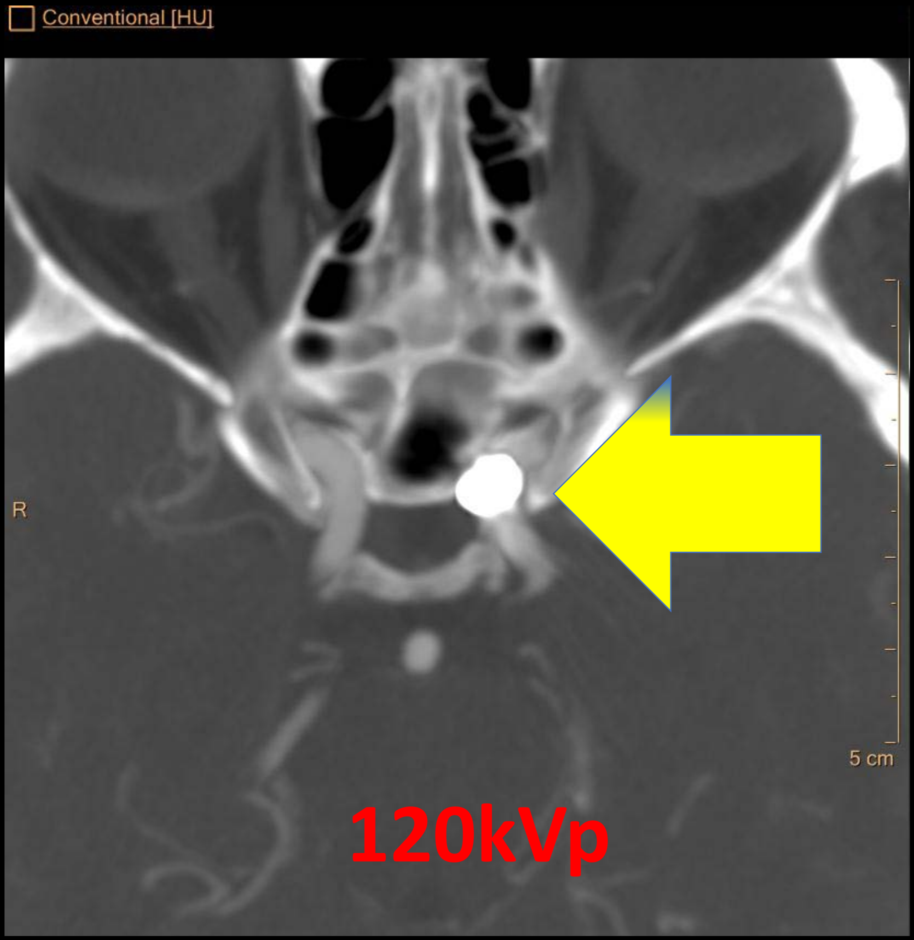
Brain IQ improvement

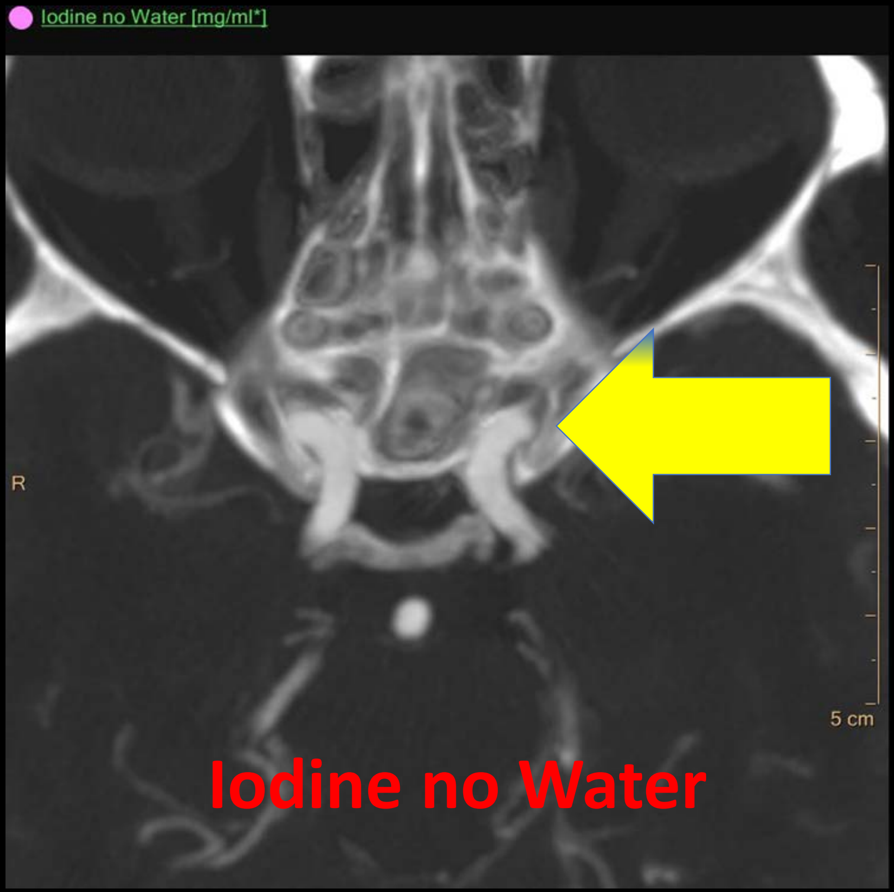


8 HU difference in the PF area of similar attenuations areas in conventional were reduced to 3 HU difference in the equivalent monoE (66).

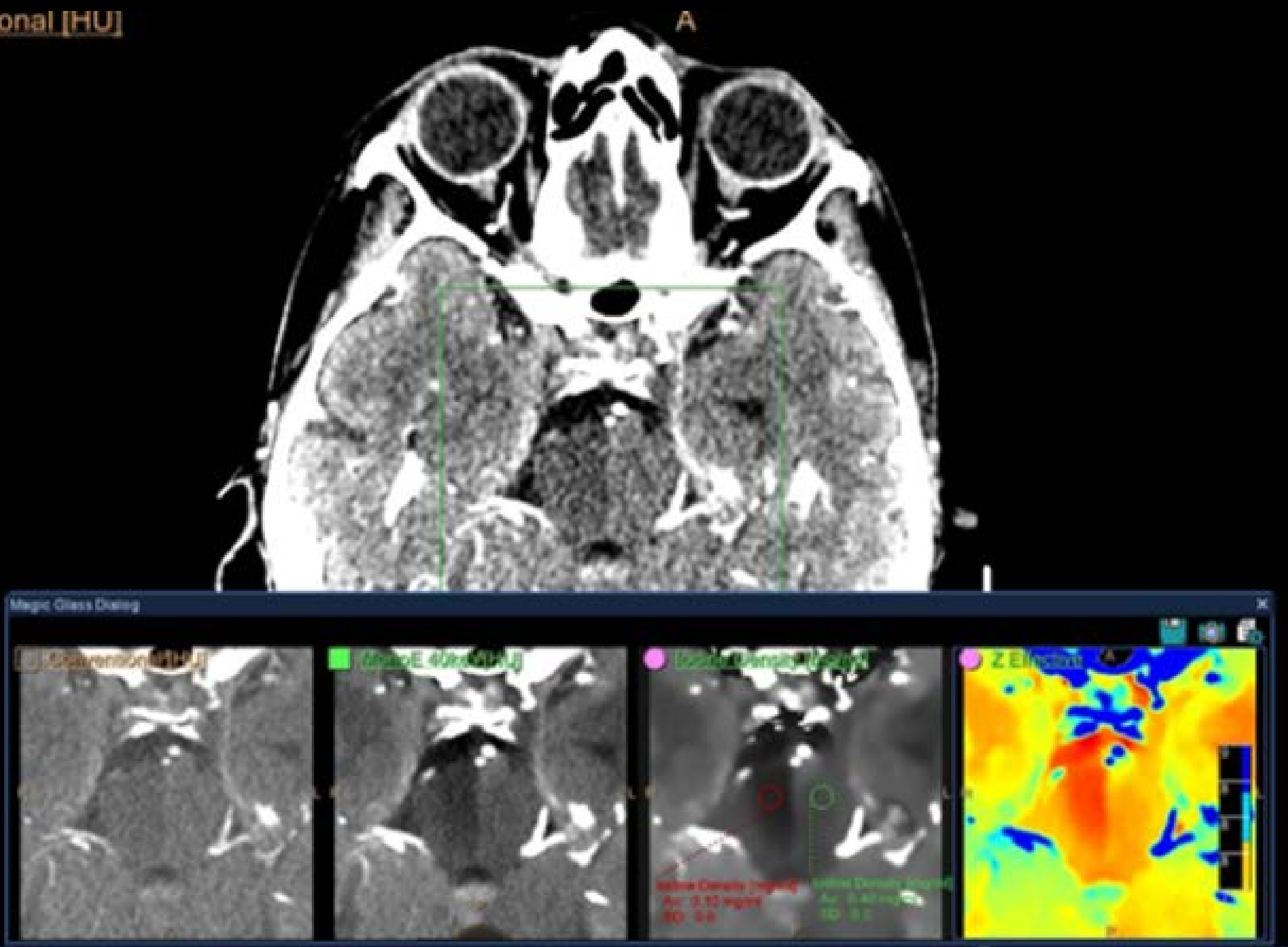
Courtesy: SNU Korea

By extraction of metallic implantation – superior visualization of ICA left





Acute stroke

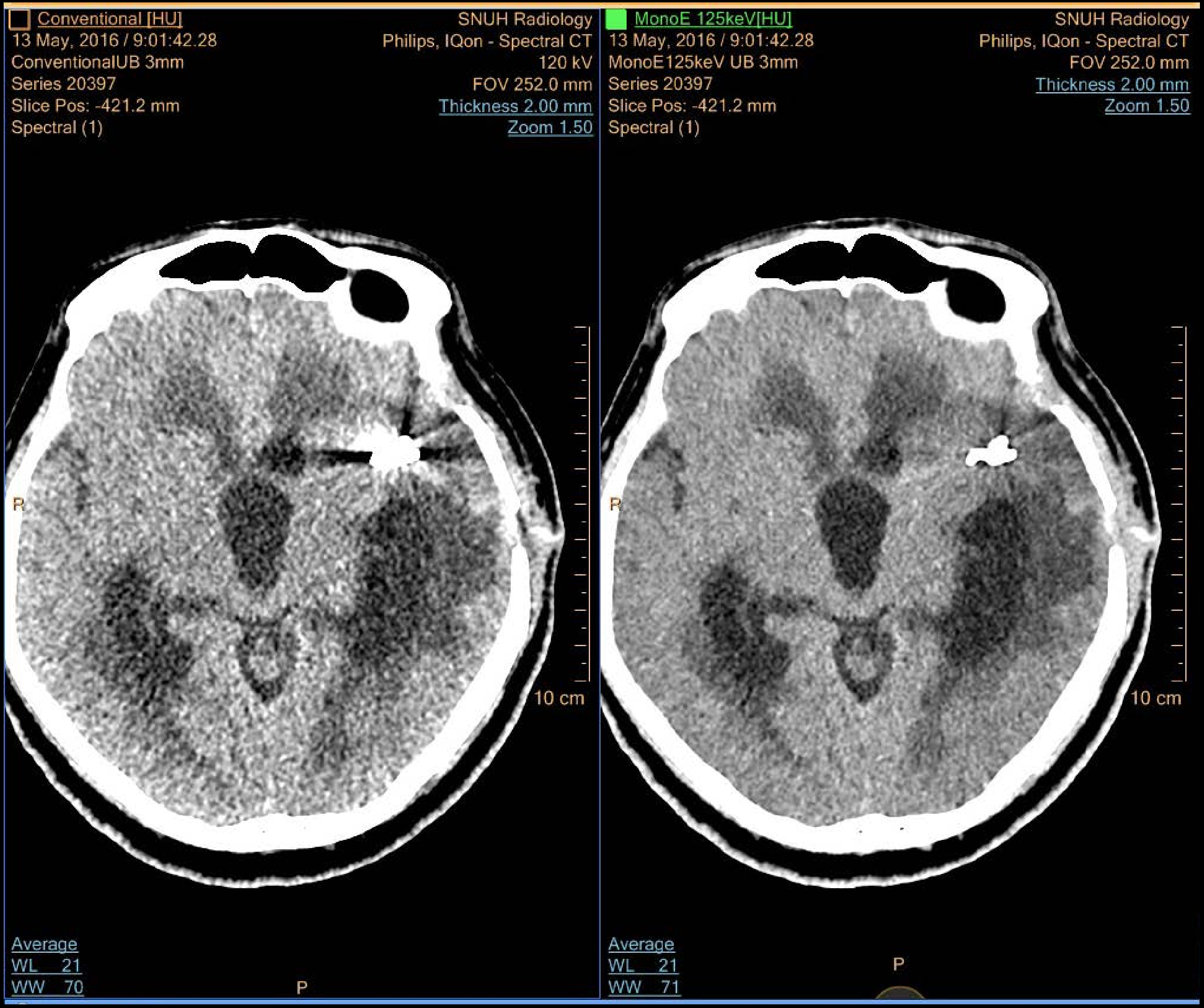


CTDIvol: 20 mGY
*DLP: 700 mGY*cm*
*Effective Dose: 1.5mSv**

Images courtesy of Cliniques universitaires St-Luc, Brussels, Belgium

Case Summary
Patient presented to the emergency department with symptoms of an acute stroke, and was referred to CT.

Brain coils

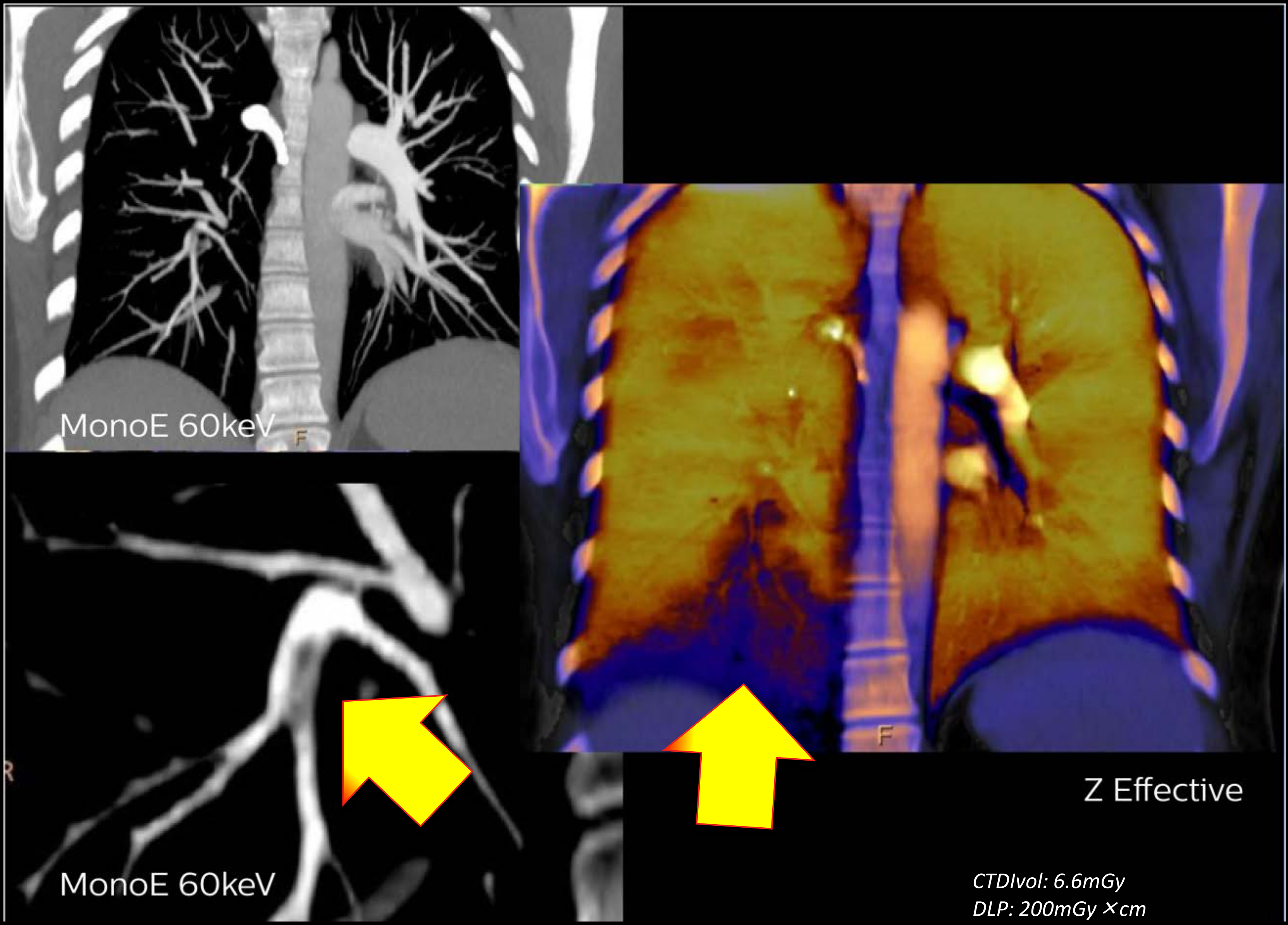


Courtesy: SNU Korea

New spectral CT IQON

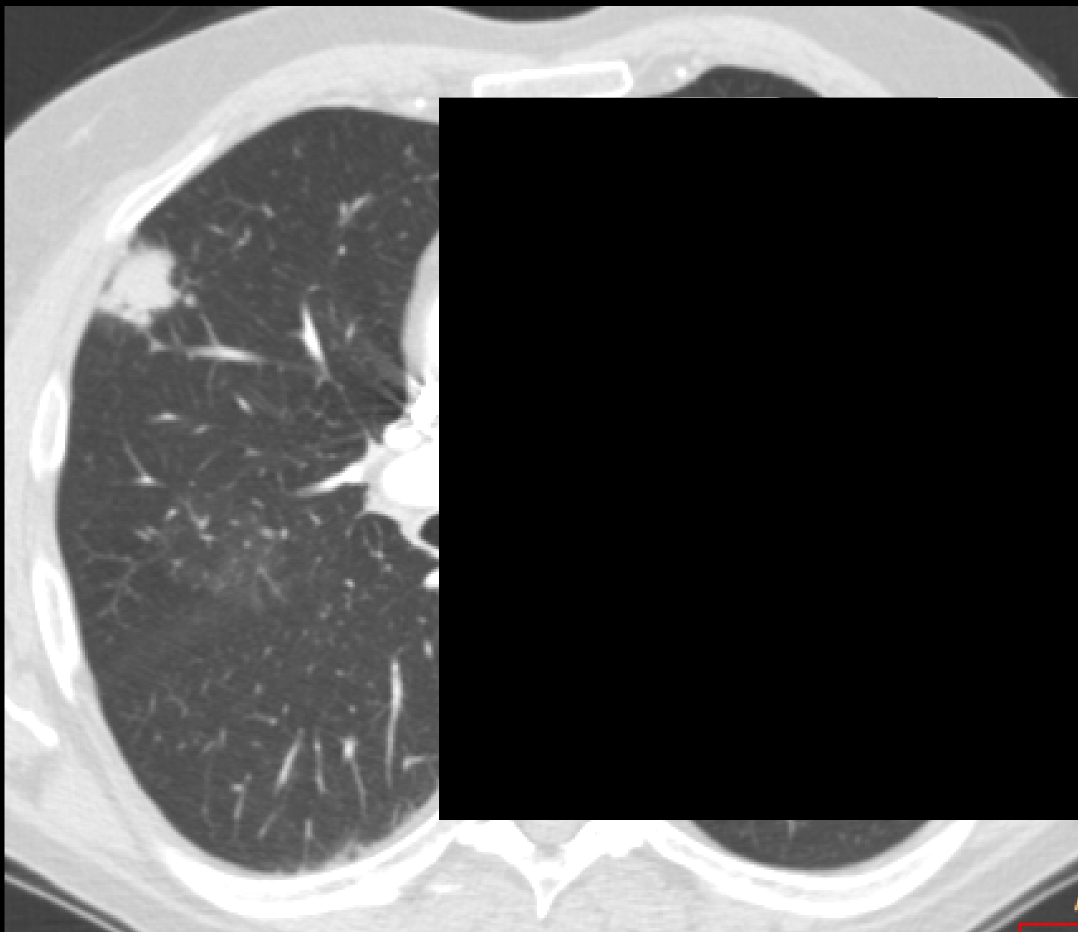
HRUDNÍK

After Z-eff map: embolus is visualized



CTDIvol: 6.6mGy
DLP: 200mGy ×cm
*Effective Dose: 3mSv (k=0.014)**

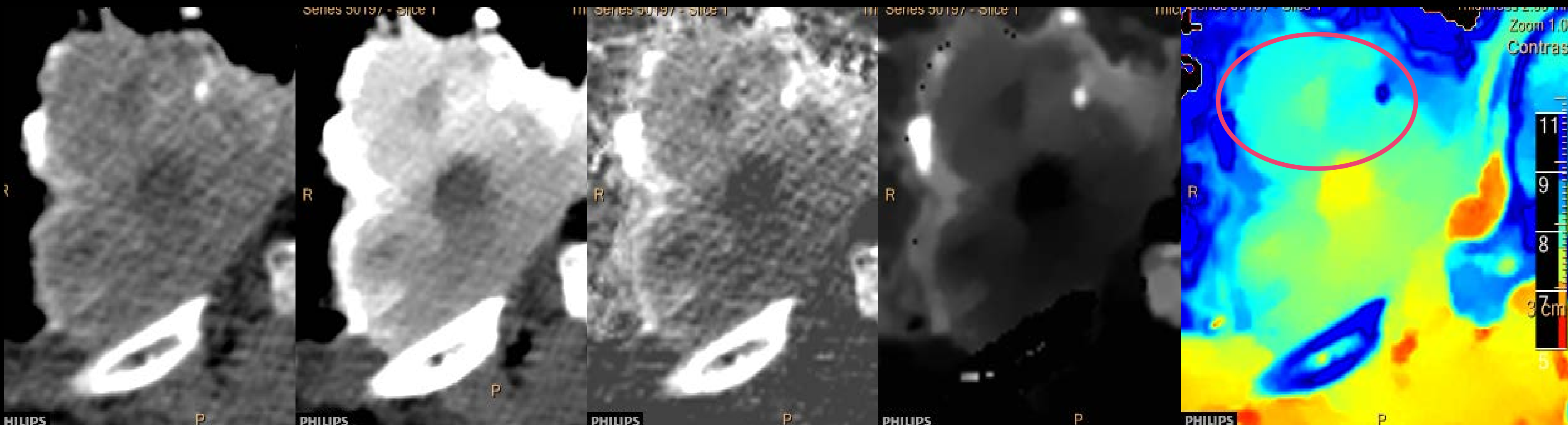
Solid lung nodule



Courtesy: Prof. F. Rassmussen, Arhus University Hospital

PHILIPS

Lung cancer – best place for biopsy



Conventional | **Mono E 40** | **Iodine no water** | **Iodine density** | **Z-effective**

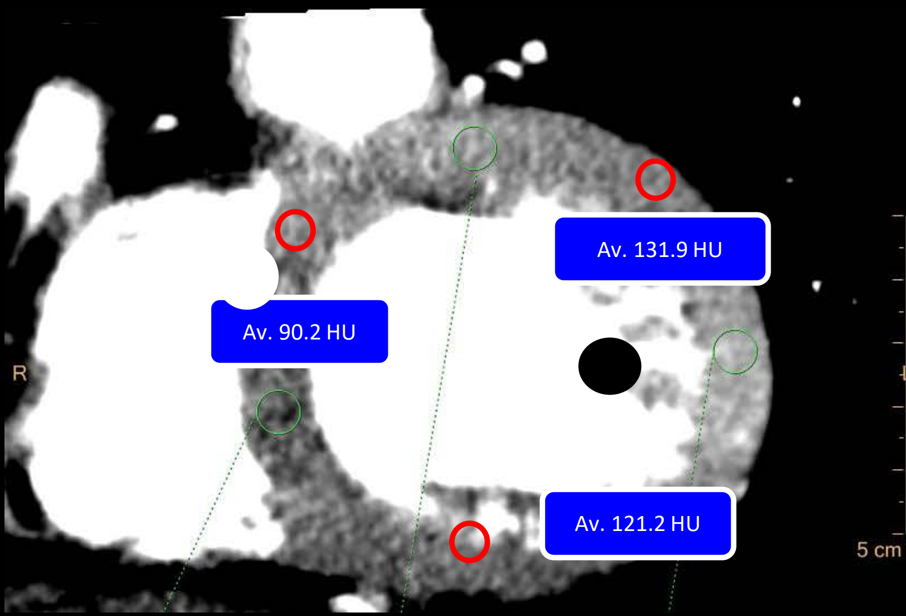
Most often is guided by DCE-CT (perfusion-blood flow maps) or PET.

Courtesy: Prof. F. Rassmussen, Arhus University Hospital

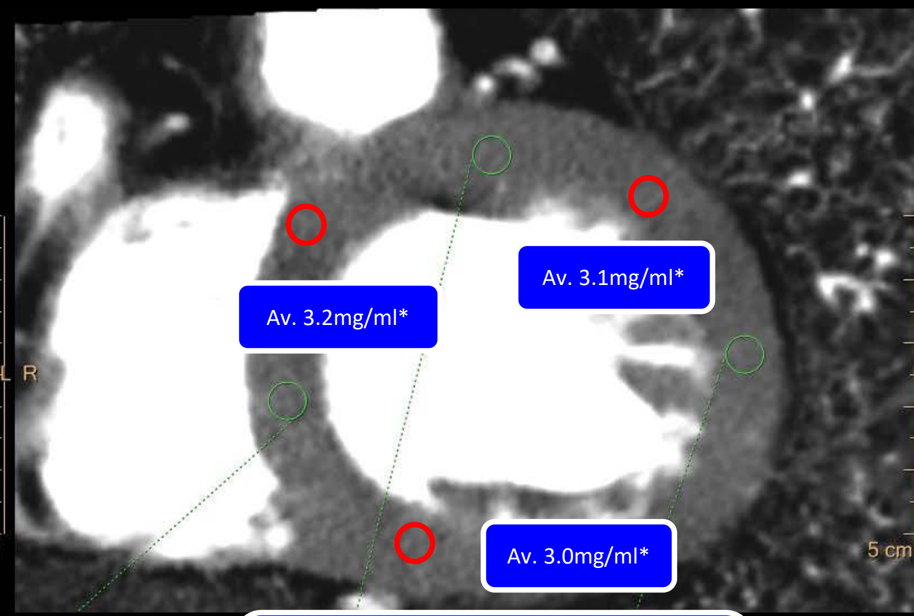
PHILIPS

Iodine Density Map showing

Consistency compared to HU



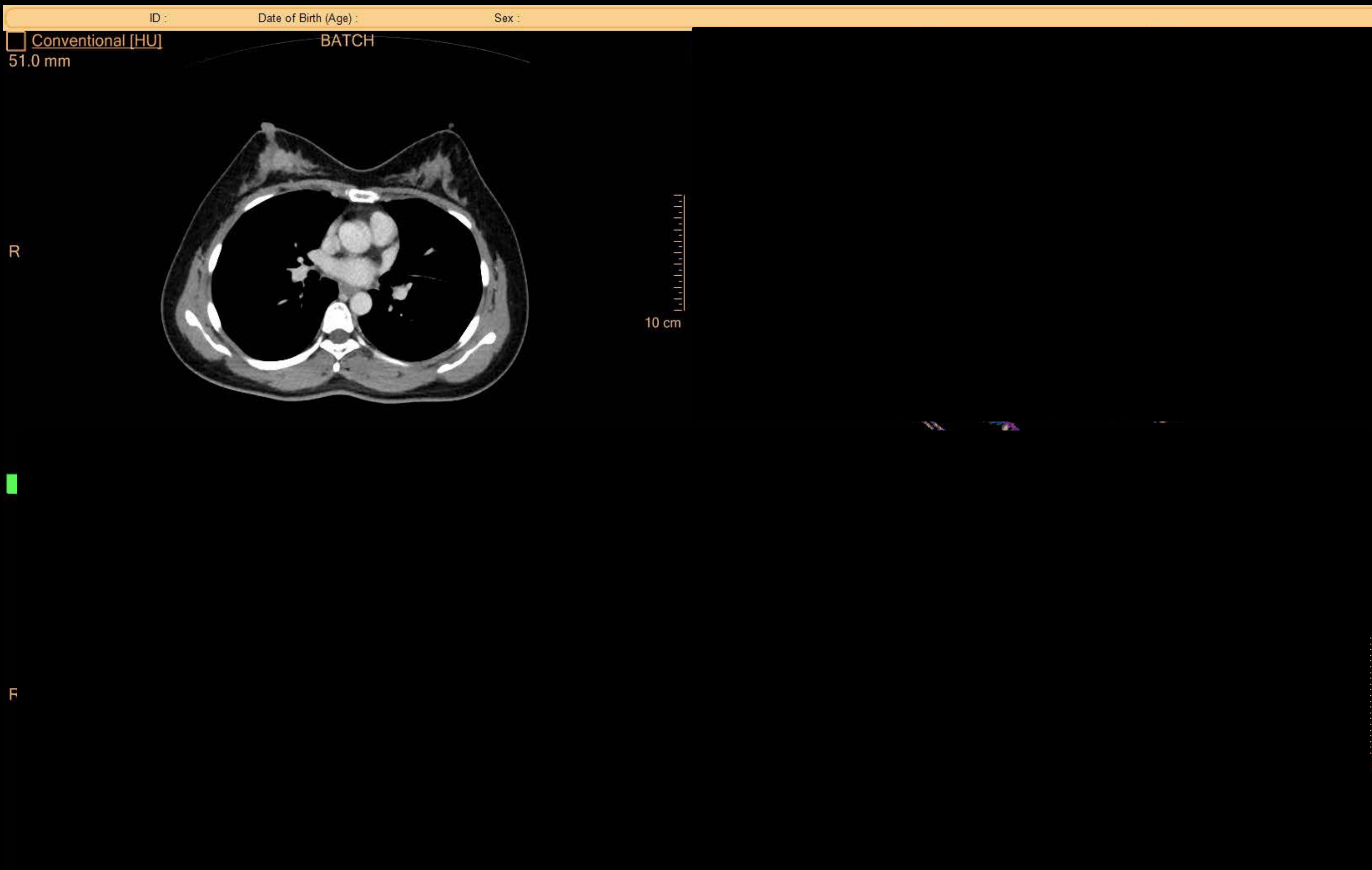
Conventional 120 kVp



Iodine Density Image

Courtesy: University Hospitals, Cleveland

Accidental CT finding-incidentaloma



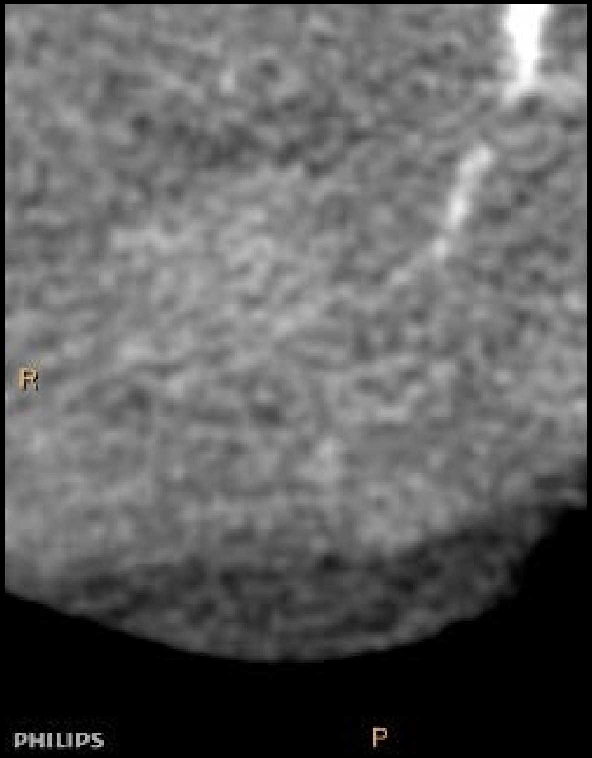
Courtesy: Korea University Hos. Ansan, Korea

BŘICHO

PÁNEV

Non uric kidney stone in the presence of contrast

HCC



Conventional **Mono E 40 KeV** **Z - effective**

Courtesy: Prof. F. Rassmussen, Arhus University Hospital

PHILIPS

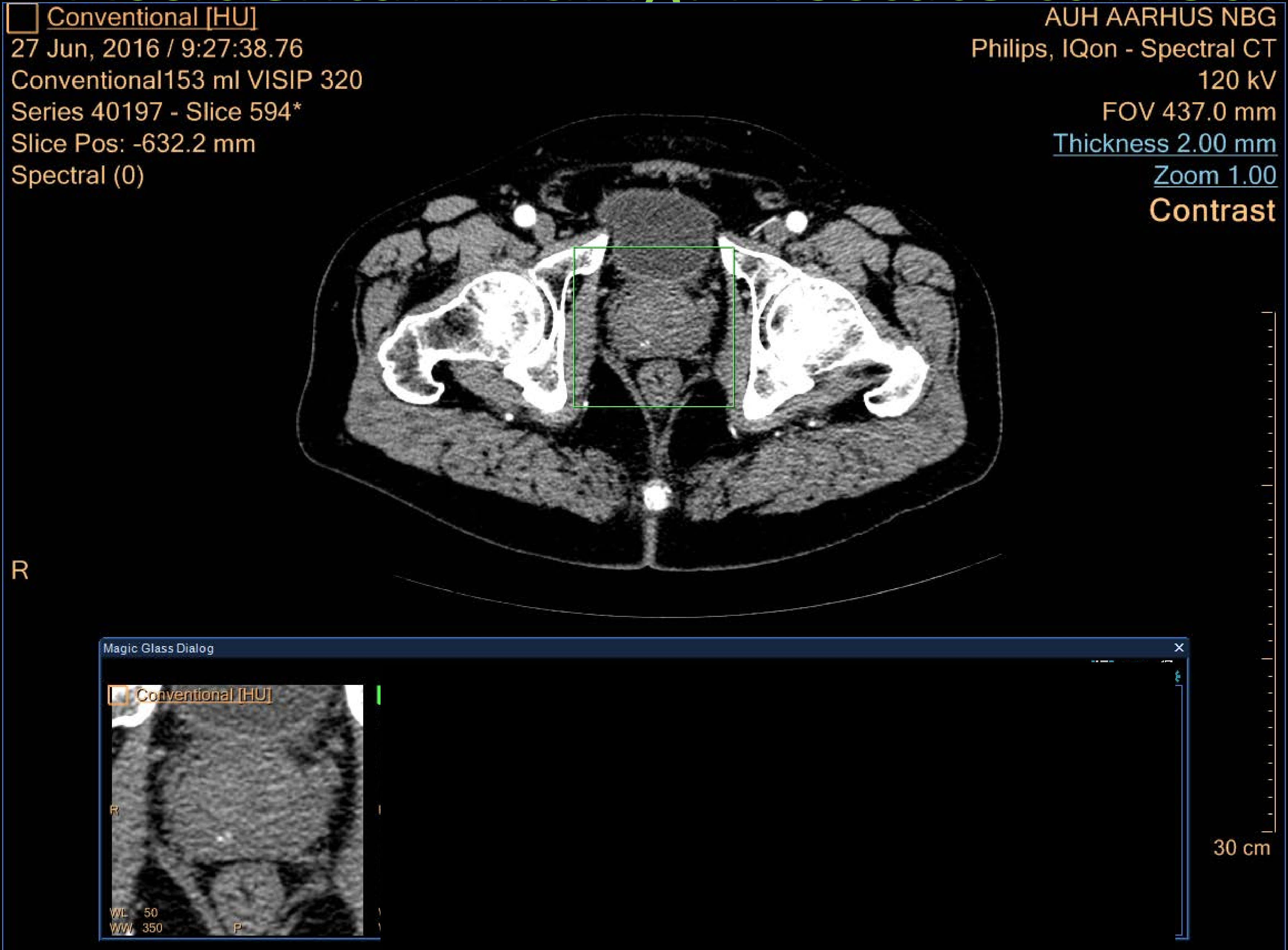
Pancreatic cancer

Conventional

Courtesy: Prof. F. Rassmussen, Arhus University Hospital

PHILIPS

Accidental finding: Prostate tumour



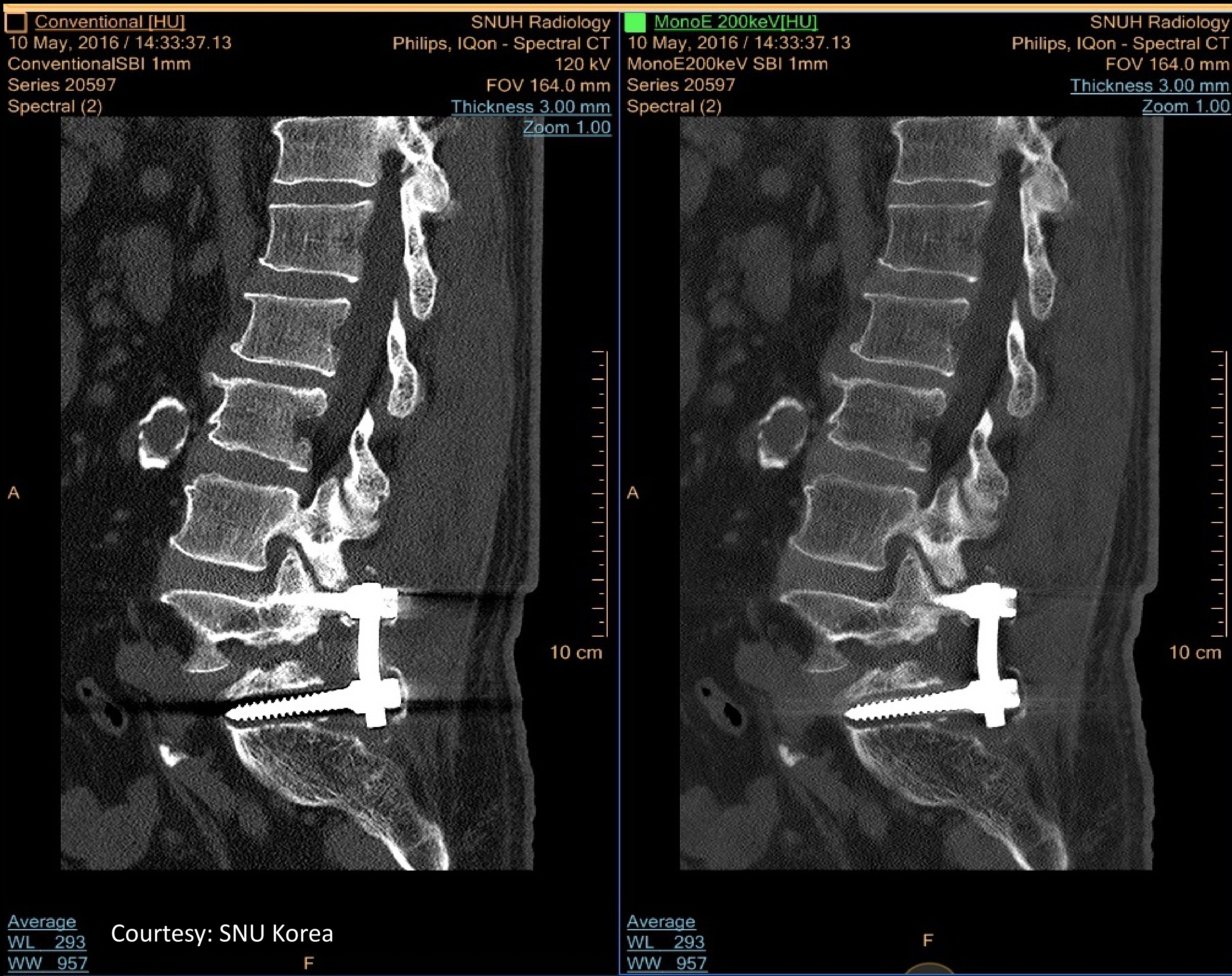
New spectral CT IQON

MSK

Ligaments visualizations

Courtesy: SNU Korea

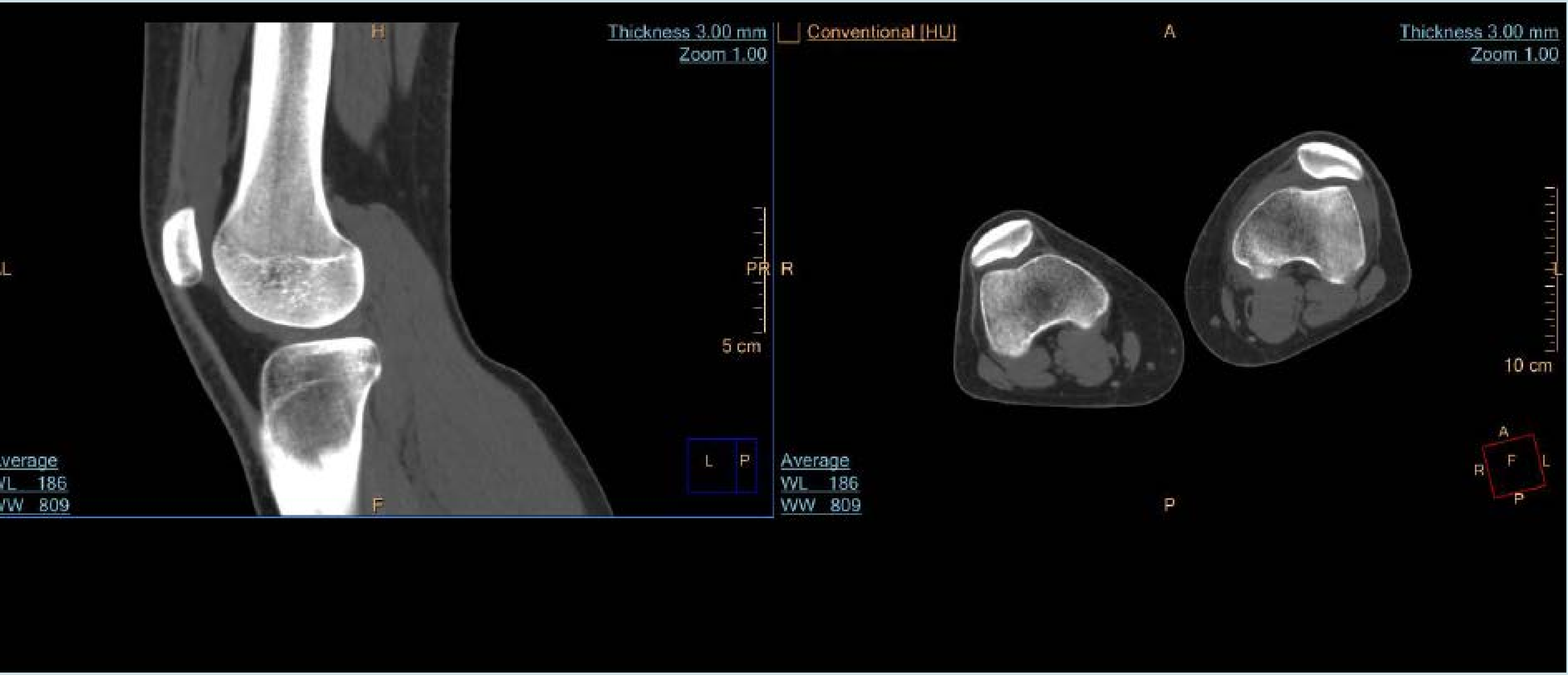
Spine meal A. reduction with high monoE+OMAR. Courtesy: SNU. Korea



Courtesy: SNU Korea

Calcium suppression - Calcium-Water material decomposition

Bone marrow edema detection

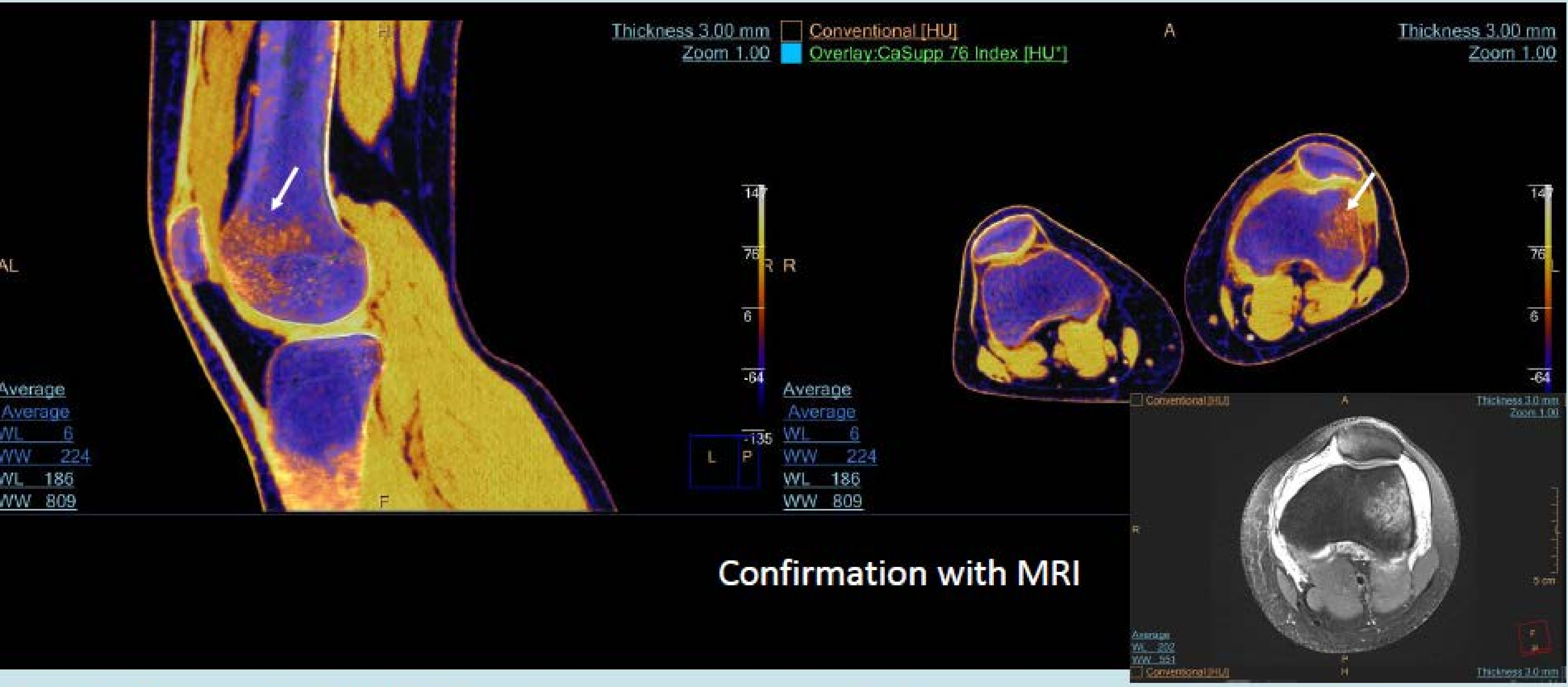


Images courtesy of: Cliniques Uiveritaires St-Luc (UCL), Brussels, Belgium

Results from case studies are not predictive of results in other cases. Results in other cases may vary.

Calcium suppression - Calcium-Water material decomposition

Bone marrow edema detection



Images courtesy of: Cliniques Uiveritaires St-Luc (UCL), Brussels, Belgium

Results from case studies are not predictive of results in other cases. Results in other cases may vary.

Přehled bodů

- Spektrální CT– cesta k innovaci + trochu teorie
- Klinicko- technické benefity spektrálního CT
- Klinické příklady aplikací spektrálního CT dle anatomie
- Jaké jsou možnosti dalších inovací

- Postprocessing /ISP
- AI v CT oblasti

Acting as New research tools

- Perfect separation due to anti-correlated noise
- Perfect calculation of beam hardening – thus better material decomposition
- New possible approaches like iron, AEF, ECV, fibrosis, 3TP perfusion, radiotherapy maps

Take home messages

- Spektrálni CT není stejné jako CT s dvojí energií
- Řešení cestou spektrálního dvojitého detektoru je technický předstupeň pro nové photocountingové CT systémy
- Spektrální informace je v každém skenu bez nutnosti selekce operátora Díky isotemporální spektrální informaci není nutno snímky registrovat
- Nejmenší isotropický spektrální voxel = zlepšení diagnostiky a diagnostické jistoty /DCE/
- Není kompromis u bariatrických pacientů, neklidných pacientů apod.
- Řešení cestou spektrálního dvojitého detektoru je nezávislé pak na technických možnostech vlastního přístroje /0,27s RT, multicycle recon apod./

Děkuji vám za milou pozornost!

Děkuji též kolegům z firmy Philips

Matthijs Kruis

Philippe Coulon

a jiným

Otázky?

Už bychom se s tím miminkem měli rozhodnout, Kájo. Mám pocit, že slyším tikat biologické hodiny...