Clinical Use of Photon Counting Detectors in CT



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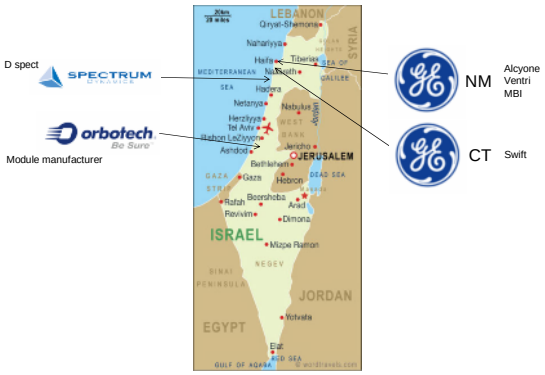
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Lev Greenberg Лев Гринберг
Jenia Kuksin Евгений Куксин
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Galit Naveh גלית נוה
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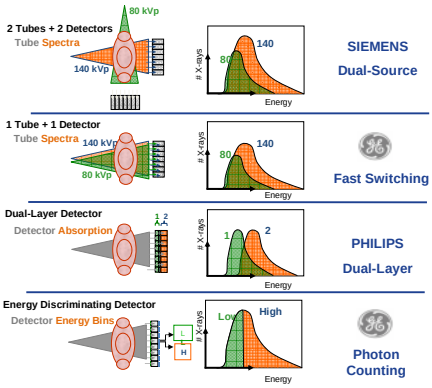
עופר בנימיניב
Ofer Benjaminov
Dept. of Diagnostic Imaging
Rabin Medical Center
Tel Aviv, Israel

GE imagination at work

Medical Photon Counting in Israel

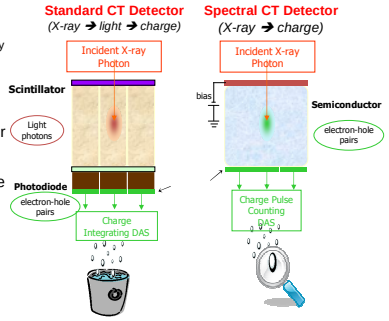


Technology Paths to Dual-Energy CT Acquisition

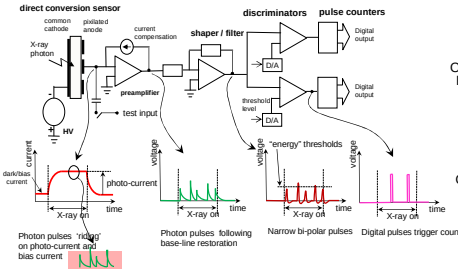


Goals of Spectral CT
Simultaneous Collection of Energy Information

- Intrinsic simplicity
  - outdates detector slicing technology
- Boost in resolution and dose efficiency
  - smaller pixels with minimal loss in 'dead-space'
- Eliminate electronic noise floor
  - digital counting of individual x-ray photons
- Gateway to ultimate MD tissue characterization
  - maximize energy separation
  - simultaneous collection for precise temporal registration



Spectral CT:
Pulse Counting Electronics

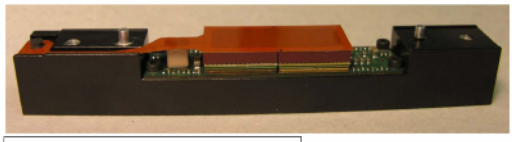


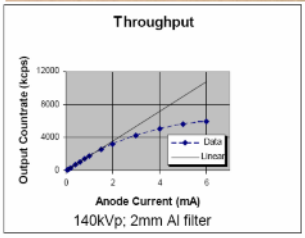
Clean Digital Signal Processing
- Incoming photon pulses stripped off flowing detector current
- Pulse heights proportional to keV
- Threshold discriminators trigger high or low digital counters

Optimum Imaging Performance
- 'zero' electronic noise floor
- Precise energy separation
- Simultaneous energy acquisition
- Fully adjustable energy bins
- Supports multiple (>2) energy acquisition

CT Detector Challenges
- Count rates >100 Mcps/mm²
- Demanding stability requirements

Detector module for CT





- 512 detector channels
- 1 mm detector pixel pitch
- 2 adjustable energy bins
- 20 keV low energy threshold
- 11x10⁶ cps/pixel

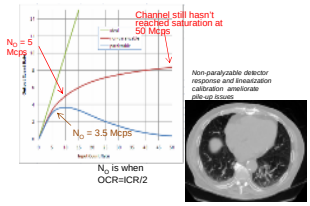
DxRay

Photon-Counting CT system: detector imaging parameters

	CT
Pixel size	1x1 mm²
Multi-slice Geometry	2D (1000x32)
Flux rate (cps/mm²)	10^5-10^8
Counts/view (1 msec)	10^2-10^5
No. of bins	2

Optimal Spectral CT Performance:
Paths to High-Flux X-ray Photon Counting

- Today's high-power scanners deliver >100 Mcps/mm² count rates at the detector
- Future systems expected to double this requirement



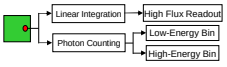
- Smaller pixels



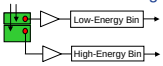
- Faster photon-counting DAS



- Hybrid Counting/Integrating

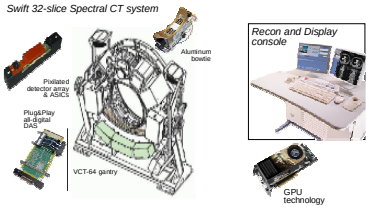


- Layered Photon-Counting



Swift Spectral CT Main Components

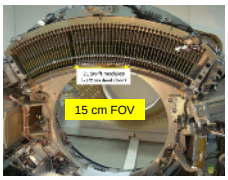
- 100% simultaneous dual-energy acquisition
- High-resolution direct-conversion detector array
- Ultra-dose-efficient photon-counting detection
- GPU-based recon and display system



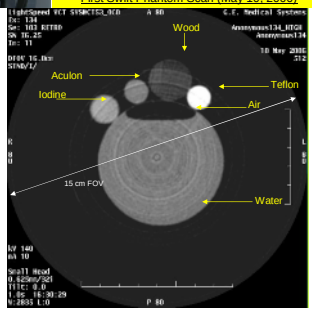


A very happy hour

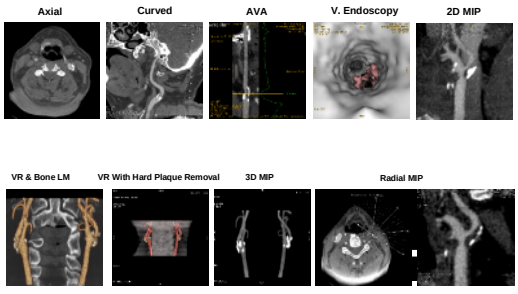
Swift: The World's First EDCT Scanner



First Swift Phantom Scan (May 10, 2006)



First Swift Patient Scanning (May 2007)



Scan parameters: Helical, 32x0.625 mm, 140 kVp, 14 mA (eff), 1-sec rotation, pitch=0.5

New images in dual energy CT

Images
- Conventional CT (HU)
- Dual Energy
  - monoE (mono-energetic equivalent (HU))
  - VNC (material density image (mg/cc))
  - Iodine (material density image (mg/cc))

Theory (dual energy)

Attenuation basis functions

•Basis processes: Photo-electric (w/o K-edge) & Compton Scatter

$\mu_T(E_1) = \mu_{PE}(E_1) + \mu_{Comp}(E_1)$

$\mu_T(E_2) = \mu_{PE}(E_2) + \mu_{Comp}(E_2)$

•Basis Materials: Al, Delrin

$\mu_{Al}(E) = x_{PE}\mu_{PE}(E) + x_{Comp}\,\mu_{Comp}(E)$

$\mu_{Delrin}(E) = y_{PE}\,\mu_{PE}(E) + y_{Comp}\,\mu_{Comp}(E)$

Material Decomposition

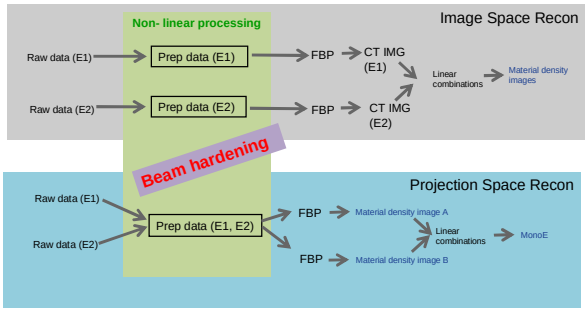
2 basis function => 2 unknowns (amount of each component) => 2 measurements @ 2 different energies

$I_1 = \int \exp(-L_{Al}\,\mu_{Al}(E_1) - L_{Del}\,\mu_{Del}(E_1))$

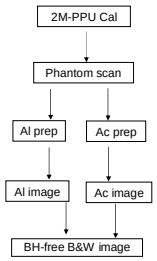
$I_2 = \int \exp(-L_{Al}\,\mu_{Al}(E_2) - L_{Del}\,\mu_{Del}(E_2))$

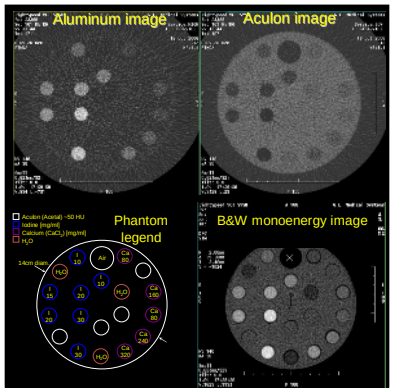
$(I_1, I_2) = G(L_{Al}, L_{Del})$ Inversion $(L_{Al}, L_{Del}) = G^{-1}(I_1, I_2)$

Proc, Recon and Images in dual Energy



2-Material Basis Decomposition





Source/Detector: influence on dose efficiency

Factor	Status (vs Conventional CT)	Function form
Detector DQE	Same; except low flux performance required for low energy beam	Empirical detector data
Bin energy separation	NEW: does not exist in single energy	E_L, E_H
Bin flux ratios	NEW: does not exist in single energy	f_L, f_H

Conventional CT

$$\sigma^2 = (1/N)\,\mathrm{DQE}$$

Dual Energy

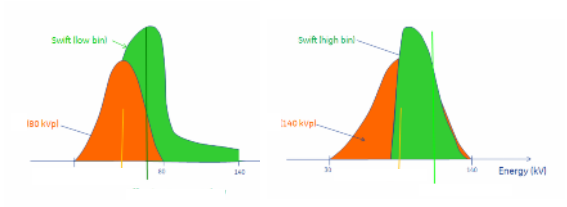
Tkaczyk et al, SPIE 2009 (7258-15)

$$\begin{pmatrix} \sigma^2_{g_A} \\ \sigma^2_{g_B} \end{pmatrix} = \frac{1/N}{(\mu_A(E_L)\mu_B(E_H) - \mu_A(E_H)\mu_B(E_L))^2} \begin{pmatrix} \mu^2_B(E_H) & \mu^2_B(E_L) \\ \mu^2_A(E_H) & \mu^2_A(E_L) \end{pmatrix} \begin{pmatrix} f^{-1}(L) \\ f^{-1}(H) \end{pmatrix} \mathrm{DQE}$$

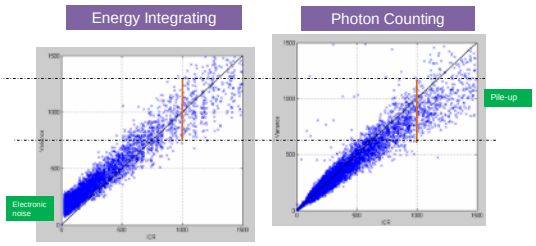
Bin energy separation

Bin flux ratios

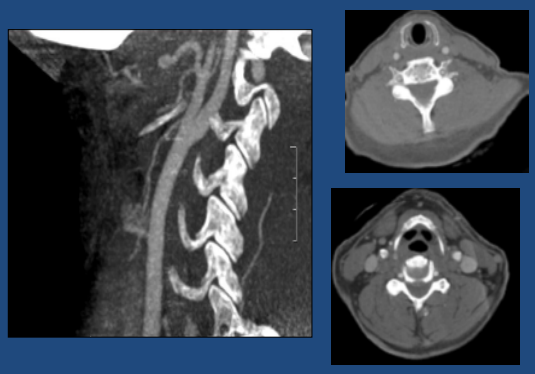
Energy separation/bin flux ratio



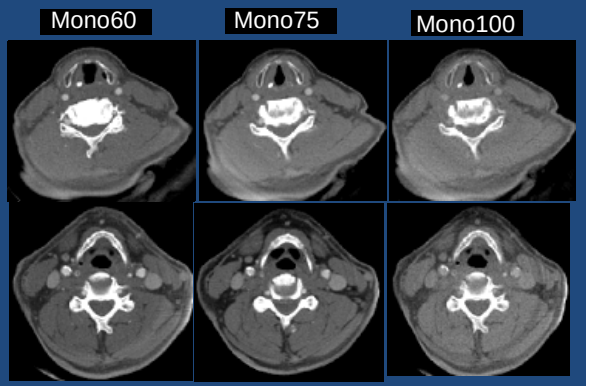
Variance vs flux (photon-counting vs energy integrating)



Carotid Arteriography



Mono-energetic Images



Virtual Non-contrast Imaging

Now you see it.



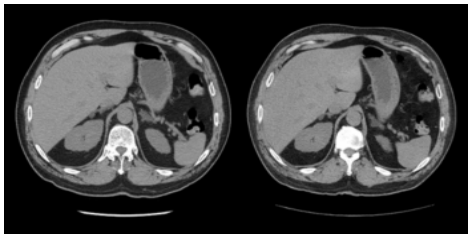
Virtual Non-contrast Imaging

Now you don't



Swift Clinical Studies:
Abdominal Imaging

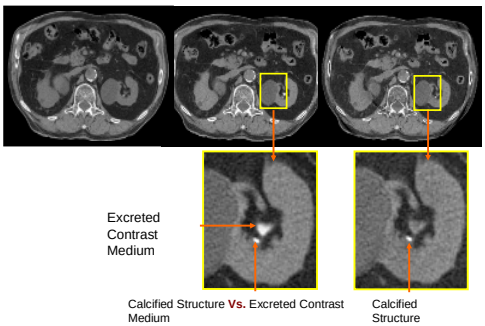
Energy Integrating | Photon Counting



Pre-contrast images

Swift Clinical Studies:
VNC Performance

TUE-MCI | Delay-MCI | Delay-VUE



Spectral CT Virtual Unenhanced processing removes iodine while preserving calcium.

15 min delay from contrast injection - images displayed with and w/o iodine.

No need for pre-contrast study.

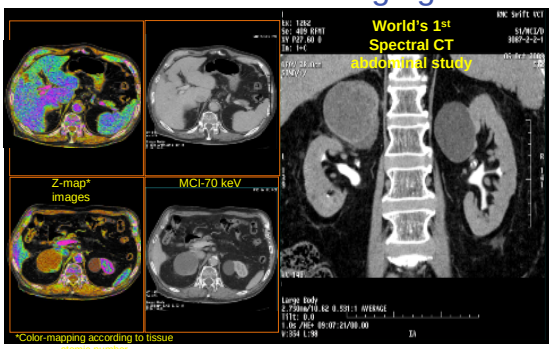
Excreted Contrast Medium

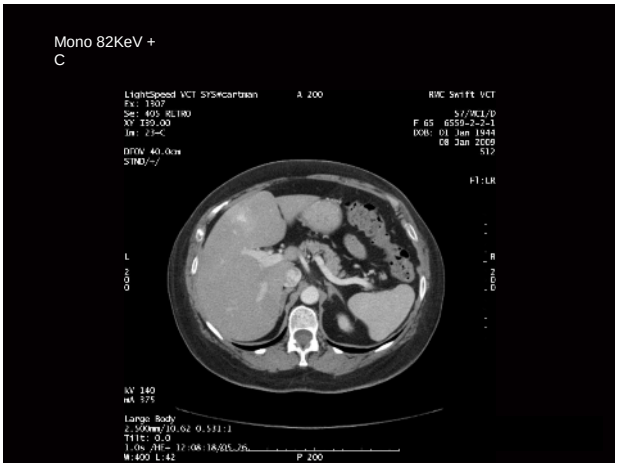
Calcified Structure **Vs.** Excreted Contrast Medium

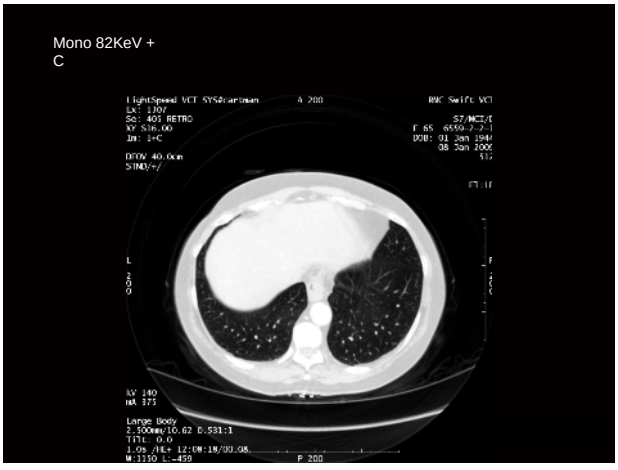
Calcified Structure

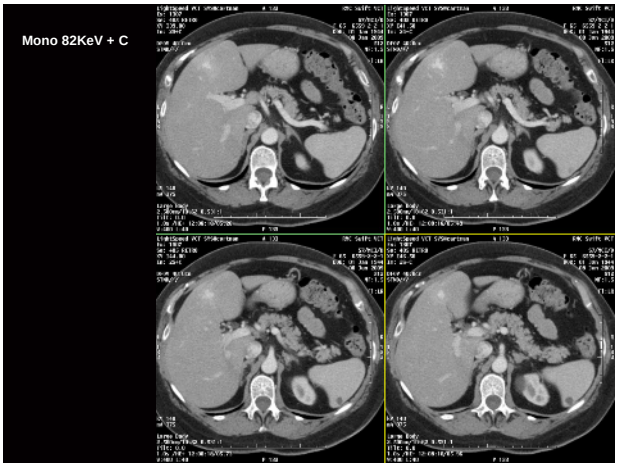
Swift Clinical Studies:

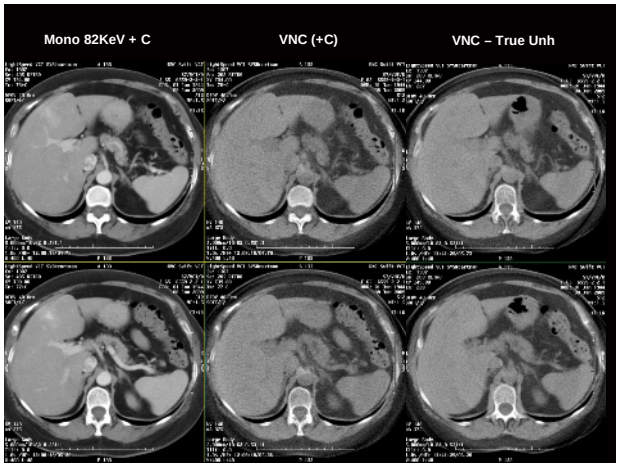
Full FOV Abdominal Imaging

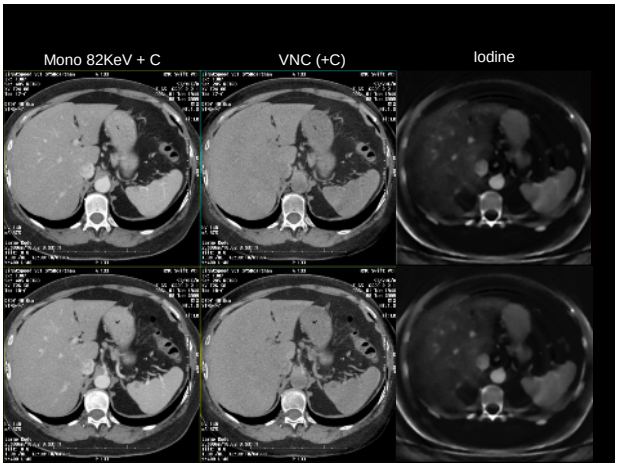


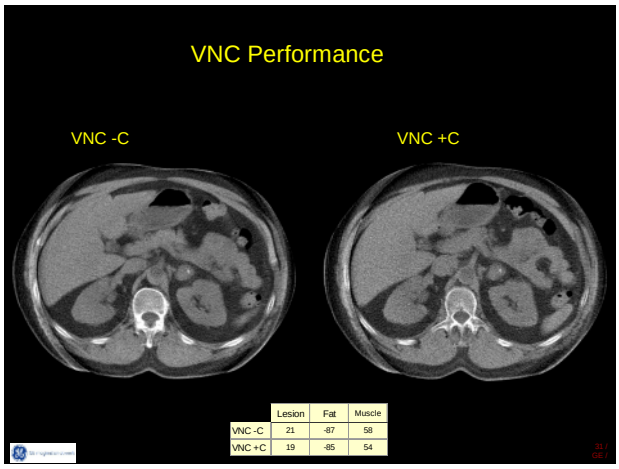


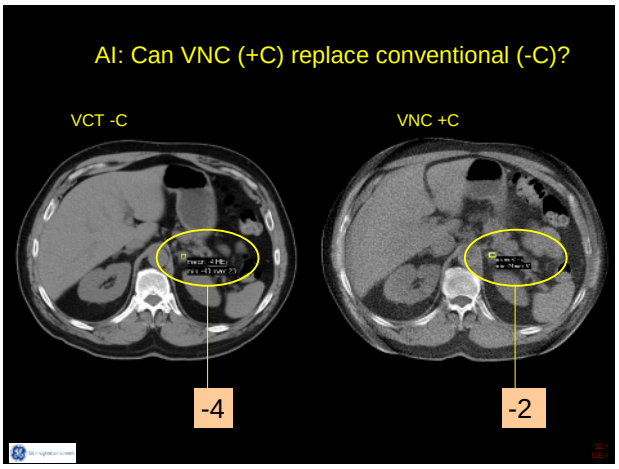





Mono 82KeV + C
VNC (+C)
VNC – True Unh


Mono 82KeV + C
VNC (+C)
Iodine


VNC Performance
VNC -C
VNC +C
Lesion
Fat
Muscle
VNC -C
21
-87
58
VNC +C
19
-85
54


AI: Can VNC (+C) replace conventional (-C)?
VCT -C
VNC +C
-4
-2

Adrenal Lesion

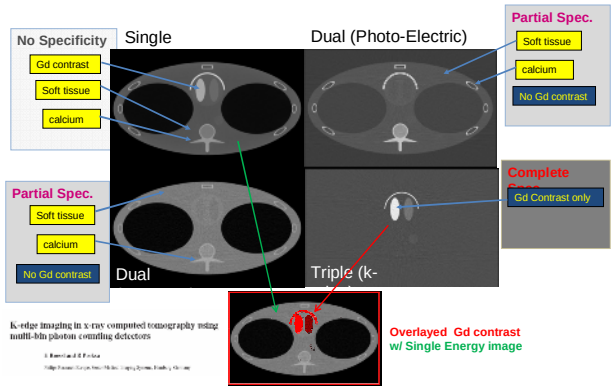
	VCT (-C)	MCI (-C)	VNC (-C)	VNC (+C)	MCI (+C)	Delayed MCI
Subject 1 (Rt. Adrenal Lesion)	22	23	20	18	25	23
Subject 2 (Lt. Upper Lesion)	-2	-2	2	1	35	N/A
Subject 2 (Lt. Lower Lesion)	30	22	20	19	60	N/A
Subject 2 (Rt Upper Lesion)	-12	-15	-14	-14	31	N/A
Subject 3 (Rt. Adrenal Lesion)	3	-5	4	5	40	19
Subject 7 (Lt. Adrenal Lesion)	3	5	7	5	57	5
Subject 8 (Rt. Adrenal Lesion)	-2	5	2	-5	45	14
Subject 8 (Lt. Adrenal Lesion)	-3	-10	1	8	30	0
Average	**5**	3	5	**5**	40	12

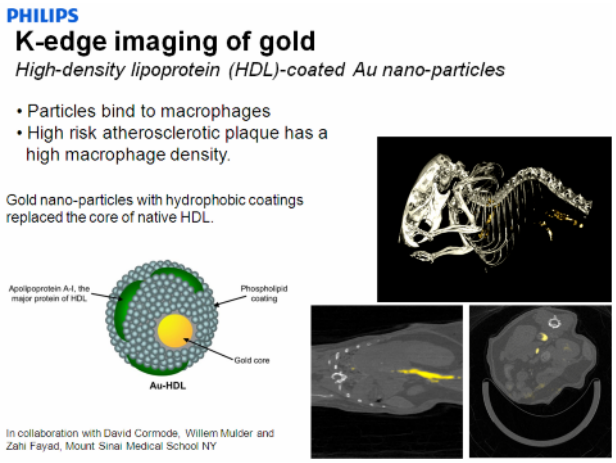
Conventional CT vs Dual Energy CT (μ vs material density)

	conv CT-C	VNC -C
Liver	51.1	55.0
Spleen	42.2	49.2
Aorta	34.2	45.4
Muscle	34.0	48.6
Retro. Fat	-101.0	-83.6
Gall Bladder	17.0	19.4
Portal vein	37.2	36.1

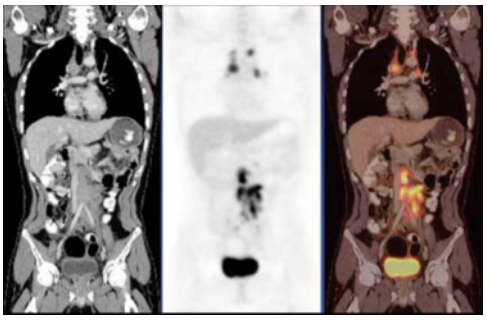
imagination at work

Complete specificity: k-edge CT (Gd contrast)





Complete specificity – PET /CT



CT PET PET/CT

Summary

- Results on clinical trials show equivalent image quality for single energy scanning and potential for low-dose scanning
- PC delivers a single-tube, single-detector configuration for high-quality dual energy CT imaging
- PC provides a path for future k-edge imaging

Great are the lights God created
Pleasant is their radiance in all the world

טובים מאורות שברא ה'
נוה זיום בכל העולם

Thank you for your attention