Multi-Energy CT:
Current status and recent innovations

Co-moderators:

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Mayo Clinic

Multi-Energy CT:
Current status and recent innovations

- Basic concepts & current implementations
  - Norbert Pelc
- Data and image analysis methods
  - Lifeng Yu
- Clinical applications
  - Cynthia McCullough
- Future directions
  - Taly Gilat Schmidt
- Panel Discussion

Multi-Energy CT:
Basic concepts & current implementations

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Cynthia McCollough: Mayo Clinic

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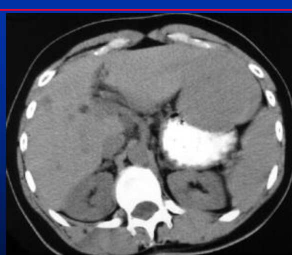
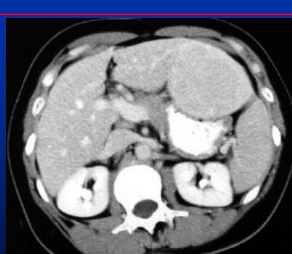
Motivation



www.uhrad.com/ctarc/ct153b2.jpg

Lower density or lower atomic number?

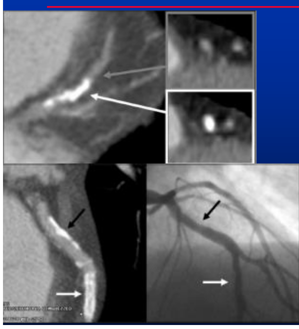
Motivation

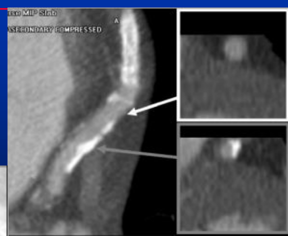


www.uhrad.com/ctarc/ct153b2.jpg

Is the HU increase due to underlying tissue property or contrast agent?

Motivation

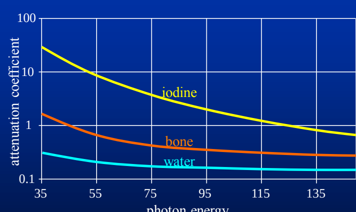




TN Sheth, et al, CARJ 56, 15, 2006.

Can we separate iodine and calcium, or reduce blooming?

Attenuation coefficients depend on photon energy



use CT measurements at multiple energies to add material specificity

Motivation

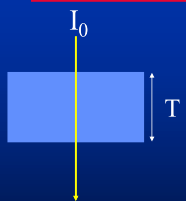
“Two pictures are taken of the same slice, one at 100 kV and the other at 140 kV...so that areas of high atomic numbers can be enhanced... Tests carried out to date have shown that iodine (Z=53) can be readily differentiated from calcium (Z=20)”.

G.N. Hounsfield, BJR 46, 1016-22, 1973.

OUTLINE

- Physical principles of multi-energy x-ray measurements
- Implementations
  - achieving spectral selectivity
  - obtaining multi-energy measurements
- Summary

attenuation and material identification



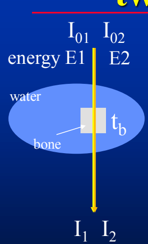
measures product of μ & T

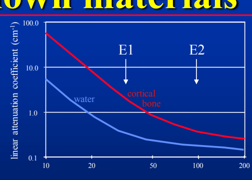
not very material specific

$$I = I_0 e^{-\mu T}$$

$$\mu T = \ln(I_0 / I)$$

unknown thickness two known materials





$$I_1 = I_{01}\, e^{-(\mu_{w1}t_w + \mu_{b1}t_b)}$$

$$I_2 = I_{02}\, e^{-(\mu_{w2}t_w + \mu_{b2}t_b)}$$

solve for t_w and/or t_b

dual energy x-ray absorptiometry (DEXA)

2 energies ⇨ 2 materials

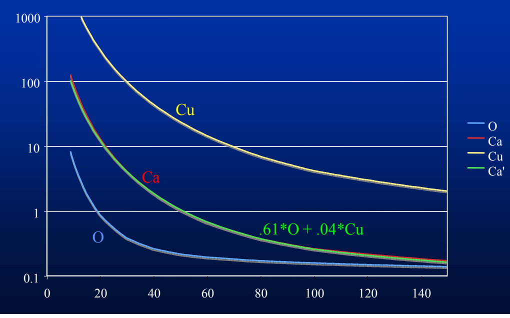
material analysis with absorptiometry

- 2 energies ⇨ 2 materials
- can we generalize this? N energies for N materials?
- limitation: two strong interaction mechanisms
  - Compton scattering and photoelectric absorption
  - Barring a K-edge in the spectrum, the energy dependence of each is the same for all elements!!

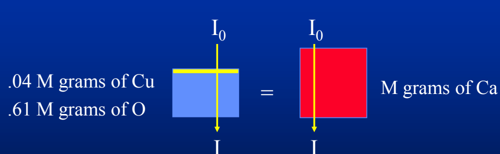
basis material decomposition:

- Attenuation of any material is ~ a weighted sum of photoelectric and Compton functions
- Any material can be modeled as a weighted sum of two other materials (basis materials)

Basis material decomposition



Basis material decomposition



Indistinguishable at any x-ray energy above their K-edge

Common “basis functions”:

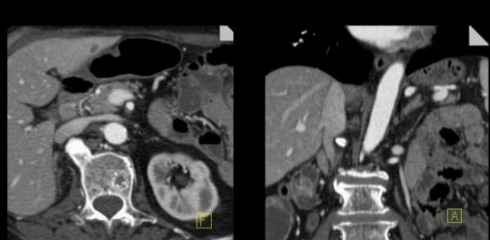
iodine and water, aluminum and plastic

photoelectric and Compton

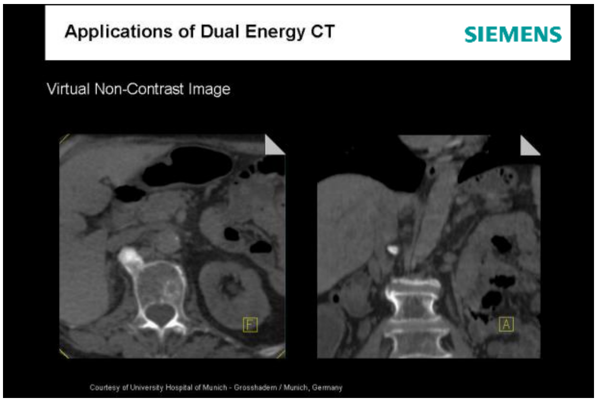
Applications of Dual Energy CT

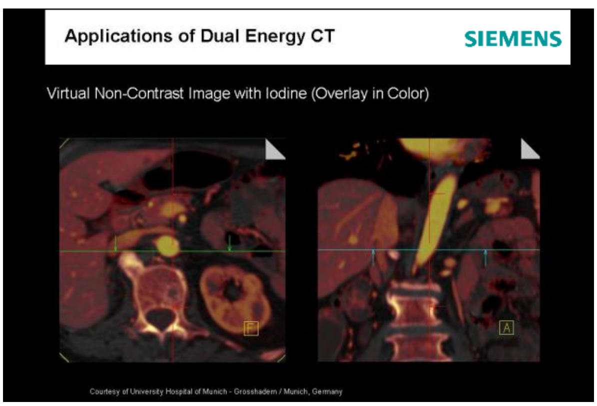
SIEMENS

80/140kV Mixed Images for regular viewing



Courtesy of University Hospital of Munich - Grosshadern / Munich, Germany

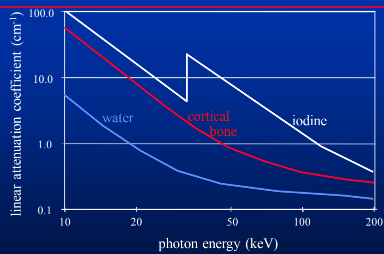




material analysis with absorptiometry

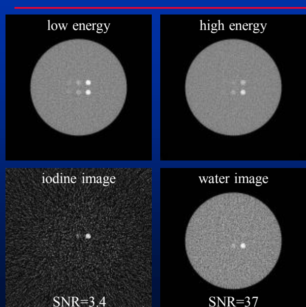
- 1 energy, constant thickness ⇨ 2 known materials (constant thickness is a constraint)
- 2 energies, unknown thickness ⇨ 2 known materials
- N energies, unknown thickness ⇨ still only 2 known materials (only 2 independent functions)
- 2 energies, constant thickness ⇨ 3 known materials (constant thickness (CT voxel) is a constraint)

K-edges



Very specific material information

Noise

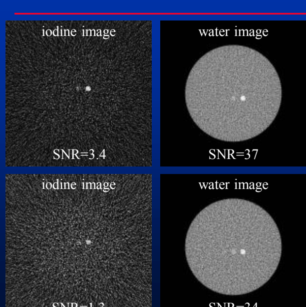


Iodine data ~
$a \bullet Data_{low} - b \bullet Data_{high}$

$\sigma^2 \sim a^2\, \sigma_{low}^2 + b^2\, \sigma_{high}^2$

depends on:
- specific energies
- allocation of dose to the two measurements

Noise depends on dose allocation



with 80/140 kVp dose allocation that maximizes iodine SNR

↓ 80 kVp dose, ↑140 kVp dose
same total dose

Spectral separation and control

- very critical for SNR efficiency, separation robustness, etc.
- implementations
  - different kVp and/or filtration
  - detectors with energy discrimination

Principle of Dual Energy CT

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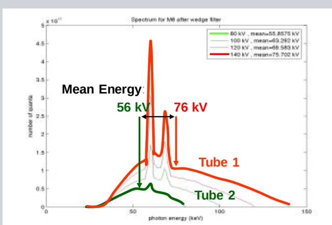
Data acquisition with different X-ray spectra: **80 kV** / **140 kV**



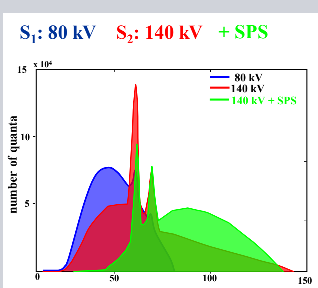
Different mean energies of the X-ray quanta

Courtesy of B. Krauss, B. Schmidt, and Th. Flohr, Siemens Medical Solutions

syngo Dual Energy - Principle of Dual Energy

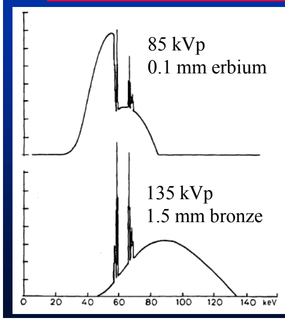
SIEMENS

SOMATOM Definition Flash



SPS= Selective Photon Shield

Dual kVp, dual filtration



- switched filtration improves separation
- different mA helps apportion dose

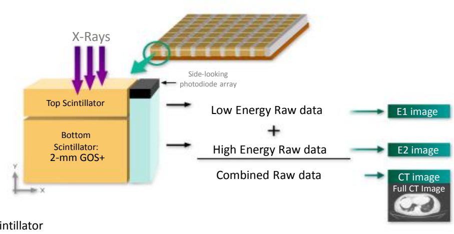
Lehmann et al: Med Phys 8, 659-67, 1981.

PHILIPS

NanoPanel Prism

Perfect alignment

Simultaneous alignment in time and space



Top scintillator
  Effective atomic number small but does not sacrifice light output
  Thickness optimized for energy separation and low-energy image noise

Bottom scintillator absorbs 99.5% of high-energy spectrum

The IQon Spectral CT is not yet CE Marked and not available for sale in all regions.
The IQon Spectral CT is pending 510(k) and not available for sale in the USA.

Layered detector

- relatively poorer spectral separation
- simultaneous dual energy sensing

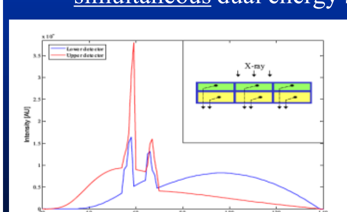
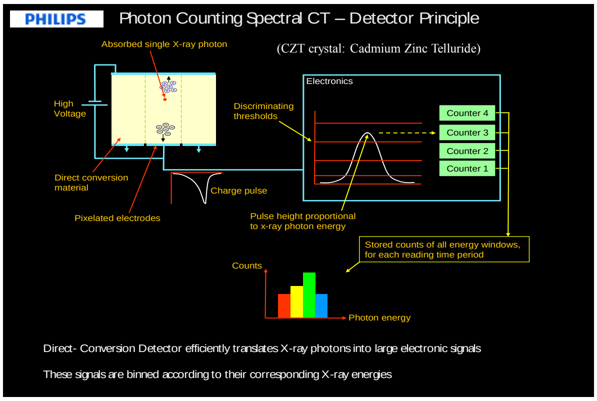


Fig. 1. The absorption spectra of the simulated dual-layer CT with tube voltage of 140 Kv. Insert shows detector configuration with partial absorber (green) and full absorber (yellow).

Carmi R, Naveh G, and Altman A: IEEE NSS M03-367, 1876-78, 2005



Spectral separation

Separation and control of the spectra is important

- reduced noise
- improved material characterization
- improved dose efficiency

Achieved by

- choice of kVp (and mAs allocation)
- use of filtration
- performance of energy discriminating detectors

Spectral separation implementations

- ideal photon counting with K-edge filter
- ideal photon counting with energy analysis
- different kVp and filtration
- different kVp
- layered detector

better spectral separation and dose efficiency

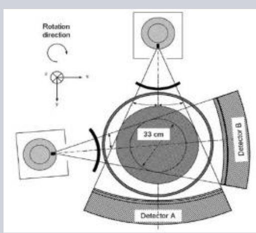
Data acquisition implementations

- Sequential scans at different kVp
  motion sensitivity > scan time
- Two sources at ~90º on the same gantry

syngo Dual Energy
- Principle of Dual Energy

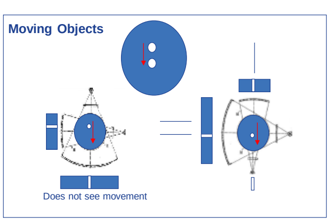
SIEMENS

SOMATOM Definition Flash

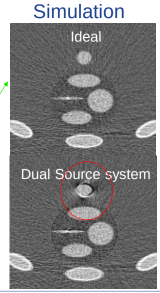


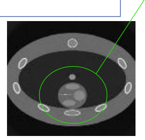
Two X-ray tubes, 1st: 80 or 100 kVp, 2nd: 140 kVp

Dual Source Challenge: Inconsistent scans



Moving Phantom Simulation





imagination at work

Courtesy of R. Senzig, GE Healthcare

Data acquisition implementations

- Sequential scans at different kVp
  motion sensitivity > scan time
- Two sources at ~90º on the same gantry
  some motion sensitivity (~ 25% T_{rot})
- Switching kVp within a single scan[1, 2]

1. Lehmann et al: Med Phys 8, 659-67, 1981.
2. Kalender et al, Med Phys 13, 334, 1986.

Rapid kVp switching Dual energy CT

- Requires fast generator and detectors
- Dose allocation controlled by dwell time
- Difficult to switch filters

Courtesy of Uri Shreter, GE Healthcare

Data acquisition implementations

- Sequential scans at different kVp
  motion sensitivity > scan time
- Two sources at 90º on the same gantry
  some motion sensitivity (~ 25% T_{rot})
- Switching kVp within a single scan
- Energy discriminating detectors
  layered detector, photon counting

better immunity to motion

Summary of commercial systems

- Siemens: two sources, different kVp (80 or 100 /140) and filtration, direct control of mA
- GE: single source with rapid switching, same filter for both kVps, control mAs by dwell time
- Philips: dual-layer detector, usual kVp mAs control
- Lots of R&D work, especially on photon counting detectors