Dual Energy CT: Implementations and Neuro Applications

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Disclosures

- DARPA
- DoD
- NIH
- Boston Scientific
- Siemens

Ether Day: October 16, 1846

Learning Objectives

- Single-energy CT
  - Limitations
- Dual-energy CT
  - Principles, Technology, Protocols, Processing
- Photon counting and Multi-spectral CT
  - Next generation CT ?
- Clinical Applications

Dual energy radiography

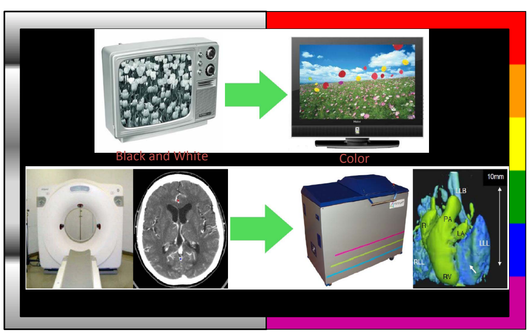
2 energies ⇨ 2 materials

Radiograph | Bone image | "Bone minic tissue" image

Armato SG III. *Experimental Lung Research.* 2004;30 (suppl 1):72-77.

Courtesy of Dr. Norbert Pelc, Stanford

Dual & Multi-spectral CT



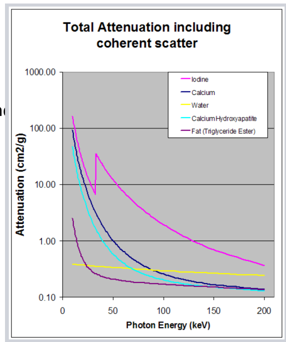
Single Energy CT

- A single CT Number (HU)
- Prior knowledge for material separation
- Unable to distinguish materials with same HU:
  - Blood vs. dilute contrast
  - Blood vs. diffuse mineralization
  - Components of plaque
  - Calcification vs. gouty tophus

Contrast staining vs Hemorrhage vs. Calcification?

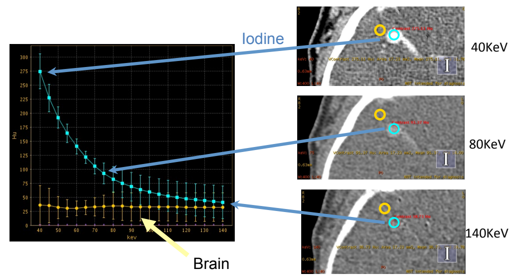
Dual Energy Principles

- Total attenuation decreases with increasing energy
- Decrease is characteristic for each material
- Depends on photon energy and material density
- X-ray absorption depends on the inner electron shells
  - DECT is sensitive to atomic number and density
  - DECT is not sensitive to chemical binding

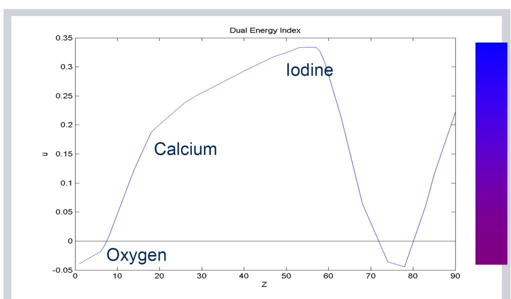


C. Leidecker, Siemens

Tissue Spectral Response



Shervin Kamalian and Michael Lev, MGH

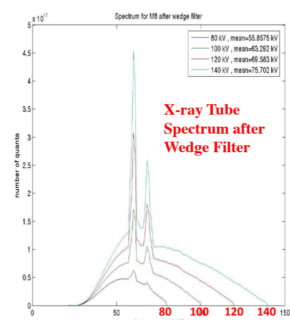


Spectral differentiation between various elements based on Dual Energy Index

(Courtesy of Christianne Leidecker, Siemens Medical Solutions)

X-ray Spectrum

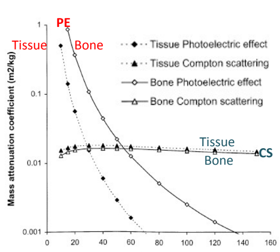
- Polychromatic
- Wide separation between 80 and 140kVp
- Filters can harden 140kVp further



Christiana Leidecker, Siemens

Dominant Attenuation Processes

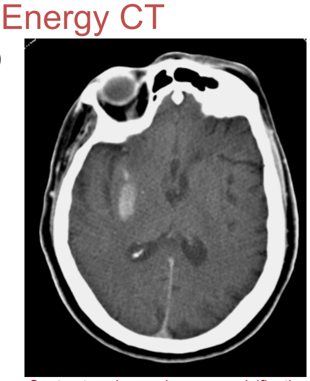
Photoelectric Effect	Compton Scattering
Dominant at lower keV	Dominant at higher keV
Large for high Z materials such as Iodine	Not too different for high vs. low Z materials
Proportional to Z^3	Depends on physical and electron density



Christiana Leidecker, Siemens

Single Energy CT

- A single CT Number (HU)
- Prior knowledge for material separation
- Unable to distinguish materials with same HU
  - Blood vs. dilute contrast
  - Blood vs. diffuse mineralization
  - Uric acid vs. Ca oxalate
  - Calcification vs. gouty tophus



Contrast vs. hemorrhage vs. calcification

Dual Energy Principles

- Total attenuation decreases with increasing energy
- Decrease is characteristic for each material
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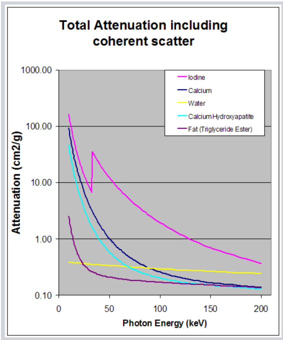
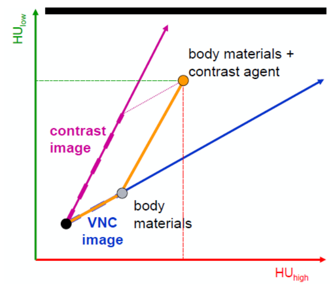


C. Leidecker, Siemens

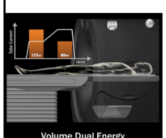
Dual Energy Theory

- Make two measurements, e.g.,
  - 80kVp
  - 140kVp
- Separate HU into
  - Tissue vs Iodine
  - Tissue vs Bone
  - Compton vs Photoelectric
- Make energy dependent simulated images

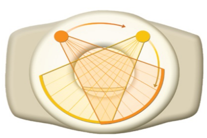


Christiana Leidecker, Siemens

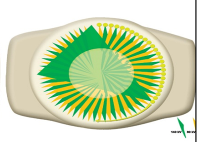
Five Implementations



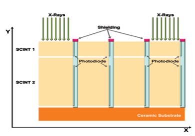
Dual Spin CT



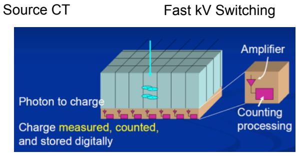
Dual Source CT



Fast kV Switching



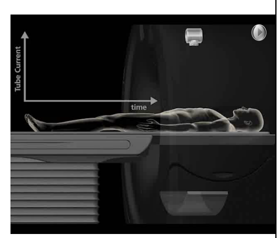
Dual Layer CT



Photon-counting CT

Dual Spin: Volume Acquisition (Toshiba)

- Wide detector array
- Low & high kV rotations
- mA automatically adjusted for similar noise
- No table movement
- Projections matched with orbital synchronization

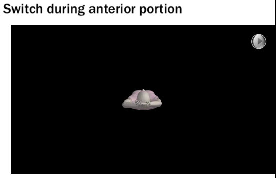


*WIP

Courtesy of Erin Angel, PhD, Toshiba

Dual Spin: Helical Acquisition (Toshiba)

- Each voxel at high and low kV
- kV and mA automatically changed
- Orbital synchronization
- Switch during anterior portion



Helical Dual Energy

*WIP

Courtesy of Erin Angel, PhD, Toshiba

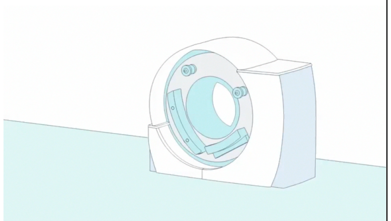
Dual Spin: Pros and Cons

- Cost effective
- Individually optimized
  - Filters
  - mA modulation
- No cross-scatter

- Delay for kV switching
- Motion between scans
- Only slice-level and not projection level decomposition

Dual Source (Siemens)

- Two imaging chains: 2 tubes & detectors
  - Dual energy mode
  - Dual source mode
  - Flash mode



Animation courtesy of
Dr. Bernhard Schmidt,
Siemens Medical Solutions

Dual Source CT

- Two imaging chains:
  - 2 x-ray tubes
  - 2 detectors
- Scan Modes
  - Dual energy mode
  - Dual source mode
  - Flash mode

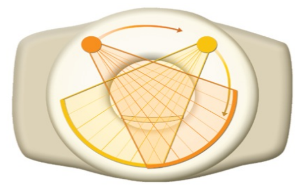
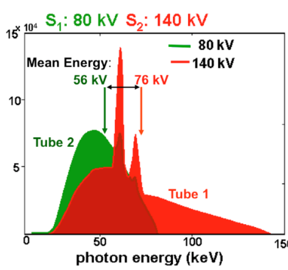
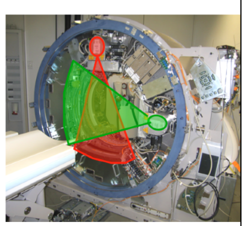


Image Acquisition Protocol

- Tube A: 80kV, 400mAs
- Tube B: 140kV (Sn), 200mAs
- Tin filter for Tube B
- 0.5s rotation, pitch 1:1
- 0.6mm slice thickness,
- CTDIvol = 68.73 mGy



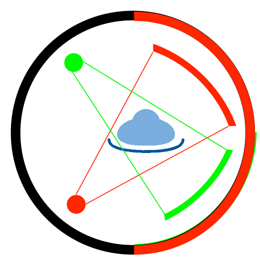


Courtesy of Bernhard Schmidt, Siemens

Dual Source (Siemens)

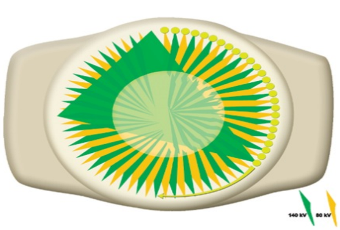
- Better spectral separation via tin filter
- Dose optimized individually for each energy
- Dose in NOT 2X w/ DSCT

- Asynchronous projections
- Cross-scatter
- Smaller FOV



Fast kV Switching (GE)

- Single Source
- Fast switching between 2 energies
- Needs innovation on both source and detector side



Fast kV Switching (GE)

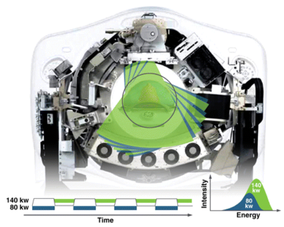
- Single Source
- Fast switching between 2 energies
- Needs innovation on both source and detector side

Animation courtesy of
GE Medical Systems

Fast kV Switching (GE)

- Projections are nearly synchronous
- Single-source ($)
- No cross-scatter

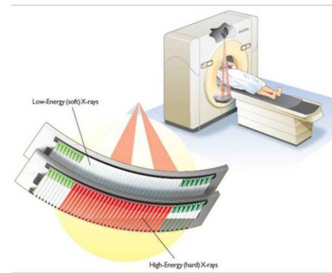
- Dose cannot be individually optimized
- Less than perfect spectral separation



GE Medical Systems

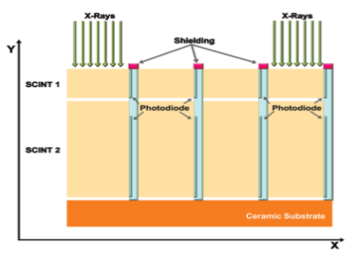
Dual Layer (Philips)

- Detector sensitive to two different energies
- Each projection has a high and low energy component



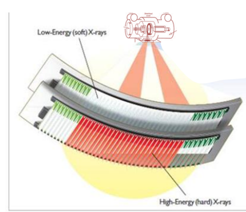
Mukta Joshi, Philips

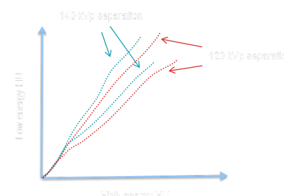
Spectral Detector CT- SDCT



Mukta Joshi, Philips

Spectral Separation



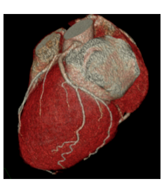


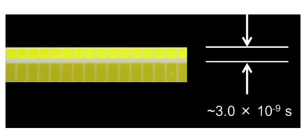
Comparable separation at 140kVp & 120 kVp

Allows Spectral CT using current protocols @ 120 kVp
Allows use of all Dose modulation tools

Mukta Joshi, Philips

Simultaneous Spectral Detection



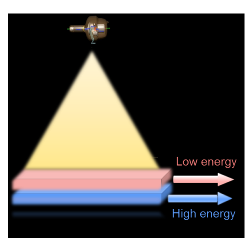


Simultaneous detection means

- Temporal spectral sampling differences reduced to effectively zero
- No rotation-time limitations (0.27 s)
- Allows 3D- and ECG-based tube-current modulation
- Projection space spectral reconstruction
- Fully quantitative spectral analysis

Mukta Joshi, Philips

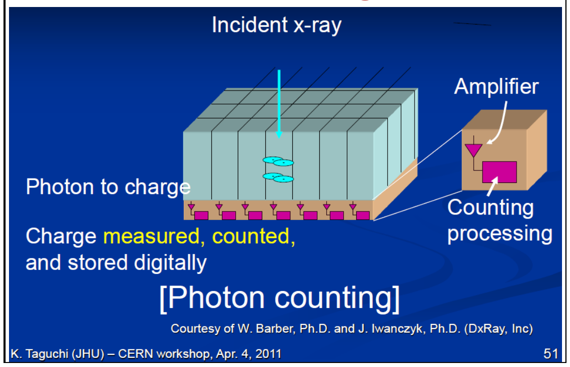
SDCT: Retrospective Spectral Imaging



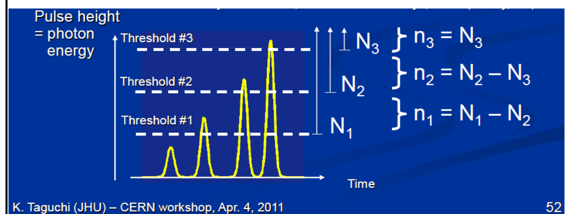
- No cross-scatter
- Perfect synchronization
- “Spectral” always on
- Workflow not disrupted

- Dose distribution and spectral separation pre-fixed by detector

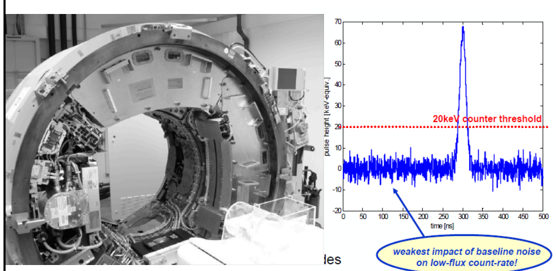
Photon Counting CT



Mechanism of Photon Counting

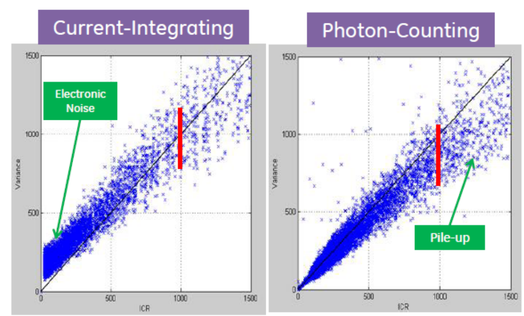


Electronic Noise



Courtesy of Stefan Kappler, Siemens

Electronic Noise



Current-integrating electronic noise is higher than expected at lower ICRs

Photon-counting N_0=5Mcps/mm² exhibits sensitivity fall-off at higher ICRs

Courtesy of Jerry Arenson, GE Medical Systems

Photon Counting

- Significant contrast improvement
- Noise reduction
- Dose reduction
- No electronic noise: ultra-low dose scans
- Multi-energy imaging

- Challenges:
  - Pile-up
  - Charge sharing
  - Polarization
  - High peak flux of CT scanning

Dual Energy CT: Implementations and Neuro Applications

Rajiv Gupta, MD, PhD

Cardiac and Neuroradiology
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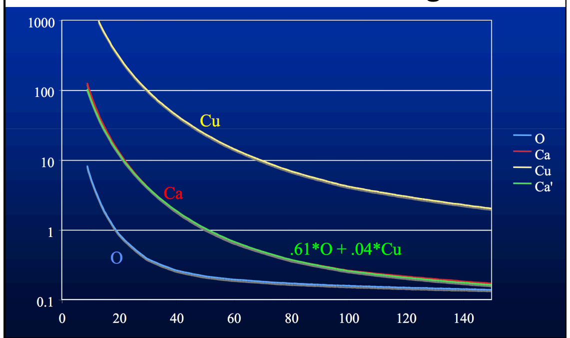
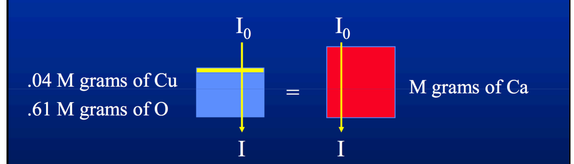
DECT: More than 2 Energies



Courtesy of Prof. Norbert Pelc, Stanford Univ.

More than 2 Energies



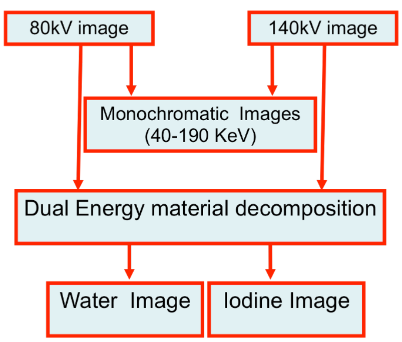
Indistinguishable at any x-ray energy above their K-edge

Common "basis materials":

iodine and water, aluminum and plastic

Courtesy of Prof. Norbert Pelc, Stanford Univ.

Post Processing



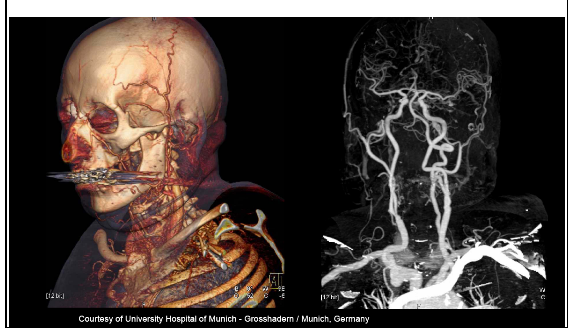
What can Multi-spectral CT do?

- Material characterization
  - Blood vs Iodine vs Calcification
  - Plaque characterization
  - Bone removal; stone characterization
  - Gout burden
- Note the limitation on the number of materials (2 or 3)
- Quantitation
  - Oncology applications
  - CT Perfusion
- Virtual monochromatic images
  - Optimal contrast viewing
  - Posterior fossa artifacts
  - Metal artifact reduction

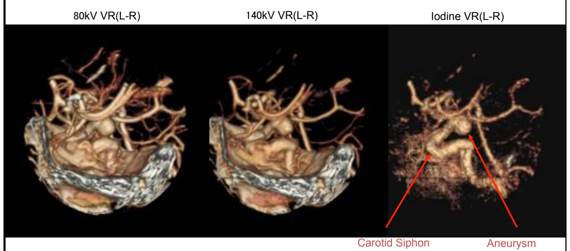
Applications

- Bone subtraction
- Optimal Contrast display
- Material Characterization
  - Iodine v. blood
  - Calcium v. blood
  - Calcium v. iodine
- Plaque characterization
- Beam Hardening artifact reduction
- Metal Artifact reduction

Bone Removal

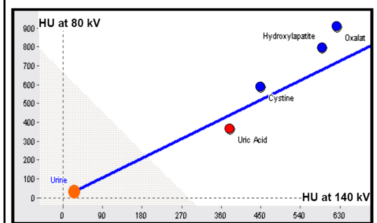


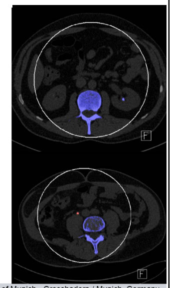
Bone Removal CTA
(Gemstone Spectral Imaging)



Courtesy of Professor S. Kuribayashi, MD, Keio Hospital, Tokyo Japan
Images acquired using Xtream HD Console and LightSpeed evaluation system

Kidney Stones

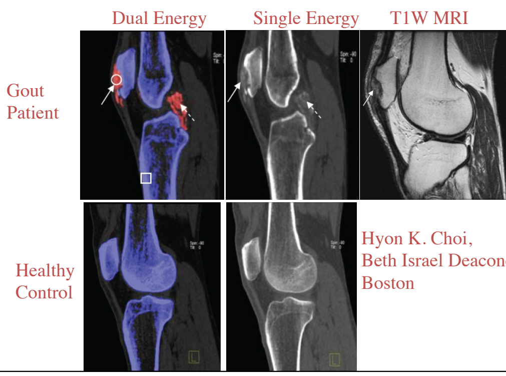




Courtesy of University Hospital of Munich - Grosshadern / Munich, Germany

- Uric acid stones can be differentiated from other renal calculi

Gout Burden

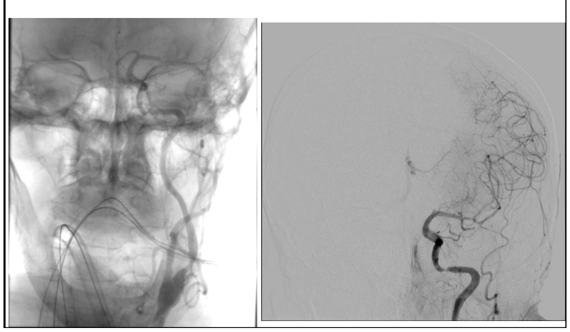


Hyon K. Choi,
Beth Israel Deaconess
Boston

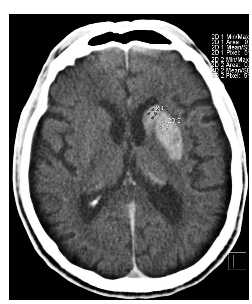
Material Characterization: Clinical Case

- 79 yo man with acute onset of right hemiparesis and aphasia
- Received IV t-PA at another hospital

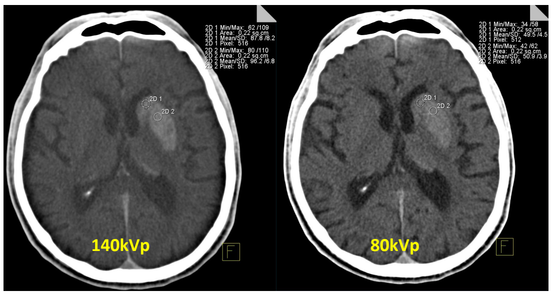
Cath Lab: Recanalization



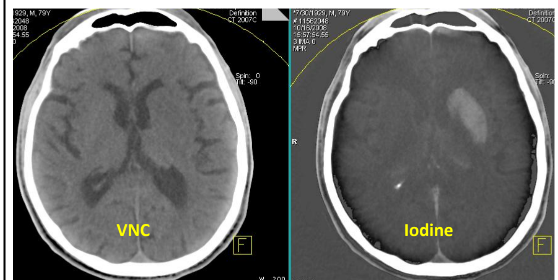
Post-op CT



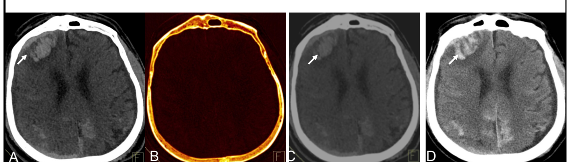
DECT Images



Virtual Non-contrast and Iodine Images

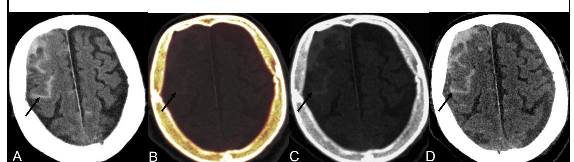


Intra-parenchymal Hemorrhage



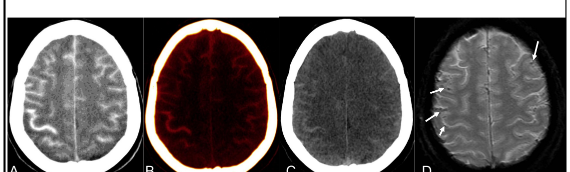
Single Energy | Iodine Overlay | Virtual Non-contrast | Follow-up Image

Subarachnoid Hemorrhage



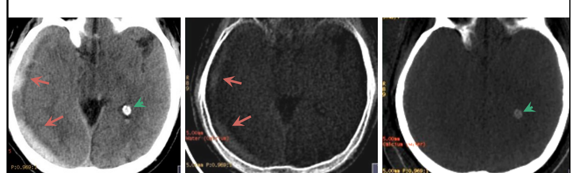
Single Energy | Iodine Overlay | Virtual Non-contrast | Follow-up Image

Subarachnoid Blood + Iodine



Single Energy | Iodine Overlay | Virtual Non-contrast | Follow-up MRI

Hemorrhage vs Calcification?

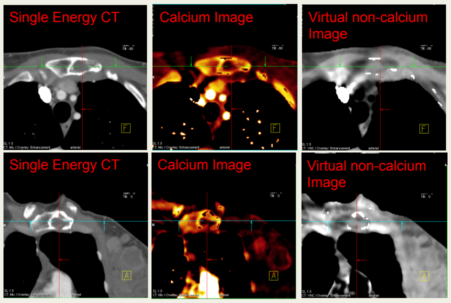


Monochromatic image 65 keV | Material density image Water (Calcium) | Material density image Calcium (Water)

Courtesy of Drs. Kamalian and Lev, MGH

Bone Mets: Iodine v. Calcium

Patient with bone metastases, under anti-angiogenesis treatment



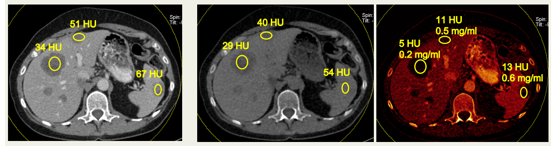
Courtesy Drs. Dinkel and Ganten, DKFZ, Heidelberg

Monitoring Treatment Response:

Iodine quantitation

DECT may show treatment response earlier than traditional modalities.

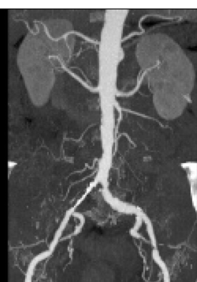
- Patient with melanoma and multiple mets
- Quantification of of Iodine in each target lesion



Single Energy CT **Virtual non-contrast CT** **Iodine Map**

Courtesy Drs. Dinkel and Ganten, DKFZ, Heidelberg

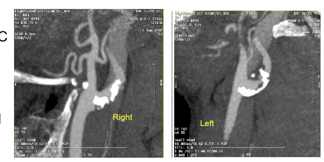
Plaque Characterization

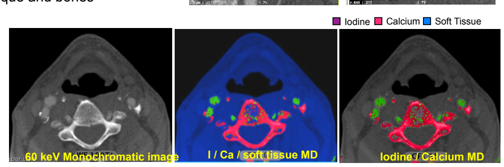


Courtesy of University Hospital of Munich - Grosshadern / Munich, Germany

Material Decomposition of ICA Plaque

- Ultra-low dose (14mA) scan
- Simultaneous Dual-Energy SPC acquisition (temporal/spatial)
- Reduced Beam Hardening artifacts with monochromatic image reconstruction
- Clear separation of iodine-filled vessels, soft tissue, calcified plaque and bones

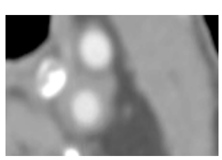




Images courtesy of Rabin Medical Center, Israel

CTA Plaque Analysis: Focal Inflammatory Enhancement?

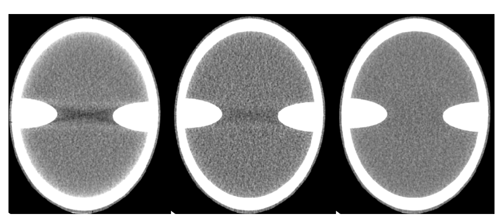
- Vasa Vasorum Enhancement
  - More common in symptomatic
    - For a 70-90% stenosis in 75 pts …
  - 50% sensitive, 80% specific
- Low Density
  - More common in symptomatic
    - For a 70-90% stenosis in 77 pts …
  - 150 vs 200 mean HU (p=0.03)
  - Ca++ favors stability
- Clear role for spectral CT!
  - 30-40 % non-diagnostic due to heavy calcification



Courtesy of Drs. Romero, Kamalian and Lev, MGH

Monochromatic Images:

Beam Hardening Correction

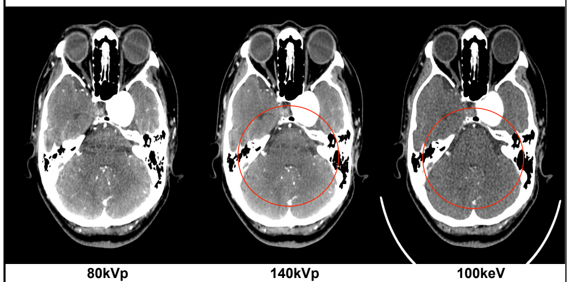


Low-spectrum High-spectrum Monochromatic 70 keV

WW – 100, WL - 40

Courtesy of Mukta Joshi, Philips

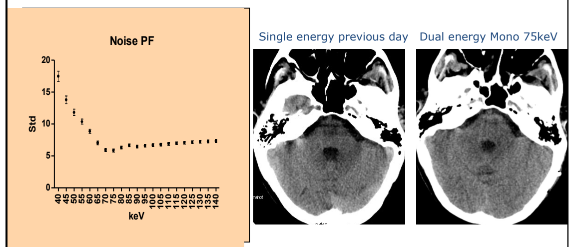
Posterior Fossa Beam Hardening Reduction



Xtream HD Console and LightSpeed Evaluation System

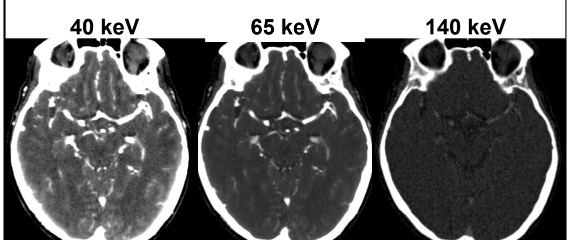
Courtesy of Dr. Amy Hara, Mayo Clinic Arizona

Monochromatic Display: Optimal Posterior Fossa Artifact Reduction

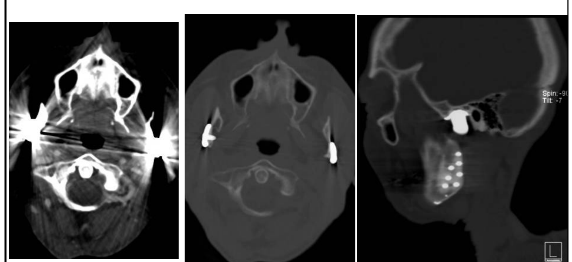


Courtesy of Drs. Kamalian and Lev, MGH

Monochromatic Images: Optimal Contrast



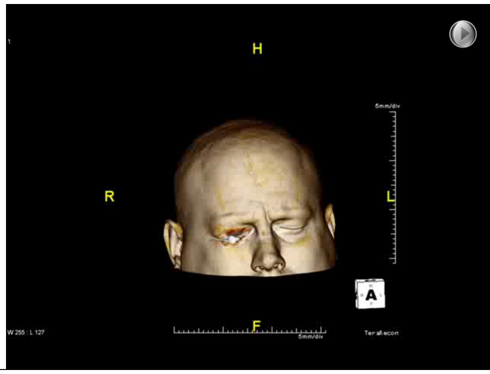
Hardware Assessment



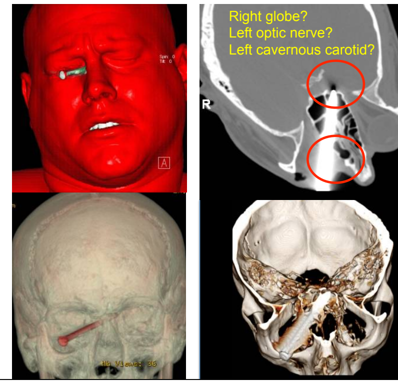
A dramatic case …

Photograph of the Patient

Gross Orientation of the Nail

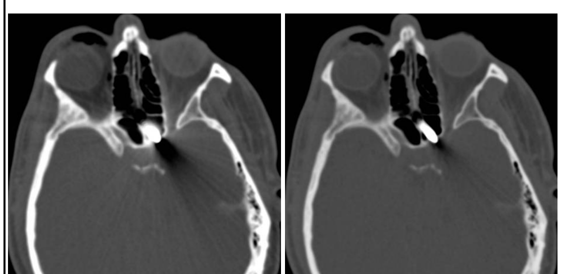


Key Questions



Single Energy Images

Dual Energy CT Acquisition

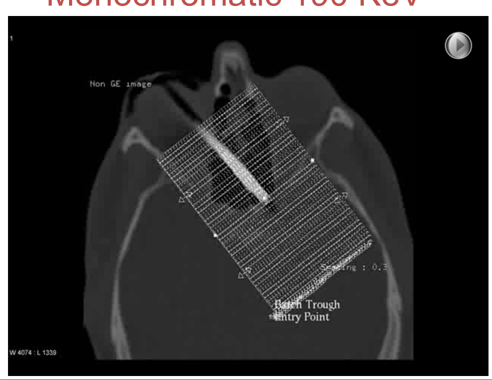


80 kV   140 kV

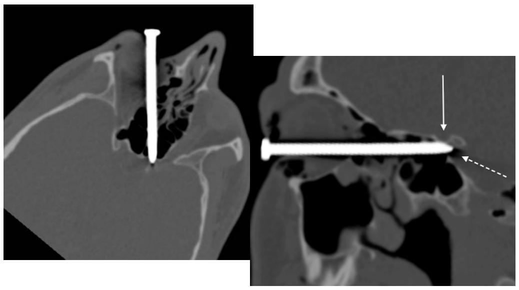
Image Processing

- Extensive metal artifacts on single energy images
- Post-processing to obtain simulated mono-energetic images
- Generated Monochromatic 190keV to suppress metal artifact

Monochromatic 190 KeV

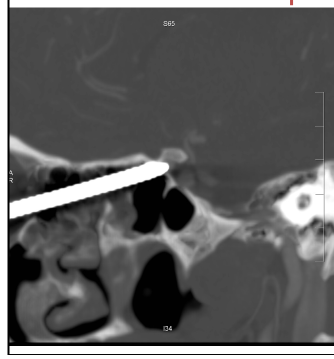


Virtual 190 keV reformats



Solid arrow: Optic nerve
Dashed arrow: Internal carotid artery

Pre-Op CTA



Nail enters the inferomedial right orbit between the right globe and the right inferior orbital rim, penetrates the right lamina papyracea, traverses the right ethmoid air cells and left sphenoid sinus and terminates at the inferior margin of the left optic groove. The tip abuts the left anterior clinoid process in close proximity to the left optic nerve and left internal carotid artery

4955492

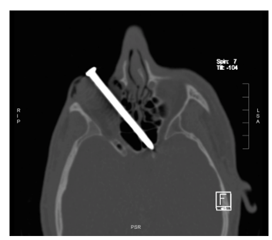
Case Records of the Massachusetts General Hospital

Radiologic Diagnosis

1. Right globe intact
2. No injury to the left optic canal or the left optic nerve
3. No injury to the left cavernous carotid

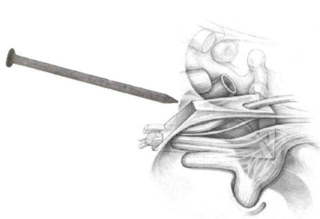
Neurosurgical Goals

- Remove the projectile without additional injury and be prepared to control potential bleeding.



Neurosurgical Goals

- Obtain proximal and distal control to “trap” the potentially injured segment and minimize possible hemorrhage



Treatment Options for the Current Case

- Pre-emptive craniotomy and neck dissection
- Prep but do not perform operative exposure
- No procedure or procedure preparation

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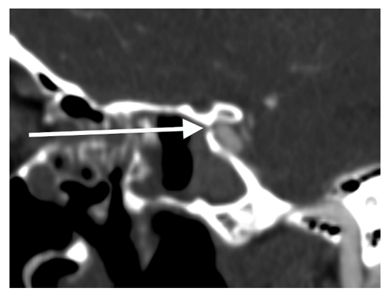
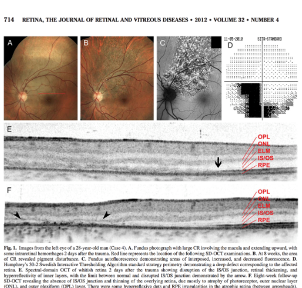
Post-Op CTA

Post removal CTA confirms relationship to optic nerve and ICA



Followup: Ophthalmology



- Commotio Retinae: Opacification, usually of outer retina structures, resulting from Blunt Trauma.
- 20/20 Vision in both eyes!

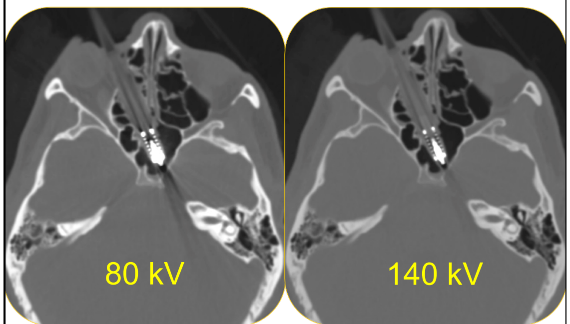
Berlin R. Zur sogenannten commotio retinae. Klin Monatsbl Augenheilkd. 1873;1:42–78.

Companion Case

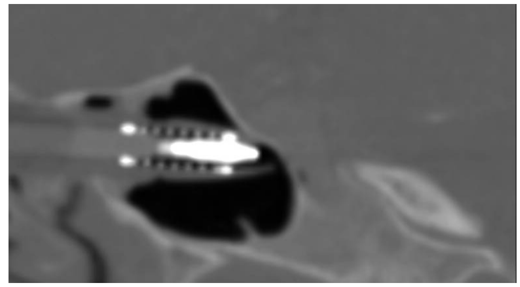
22 year old pt after suicide attempt in Psychiatry Ward

- Ran into the wall with a ball point pen aligned with the right eye
- Scanned on Siemens Definition Flash
  - 80kVp
  - 140kVp with Sn

Dual Energy CT

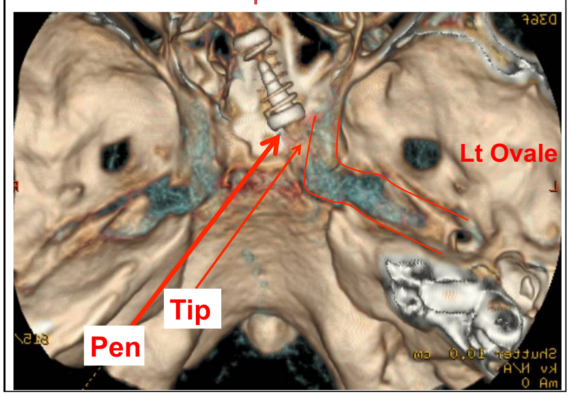


Pen v. Eye



Pen v. Eye

Top View



Conclusion

- DECT has many neuro application:
  - Bone subtraction
  - Material Characterization
    - Iodine v. blood
    - Calcium v. blood
    - Calcium v. iodine
  - Carotid plaque characterization
  - Beam Hardening in posterior fossa
  - Optimal contrast
  - Metal Artifact reduction
- Quantitative tool