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CT Clinical Innovation Center

Multi-Energy CT: Principles, Processing and Clinical Applications

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Clinical Motivation

- CT number depends on x-ray attenuation
  - Physical density (g/cm^3) [electron-densit
  - Atomic number (Z)
- Different materials can have the same CT number if atomic number differences are offset by appropriate density differences

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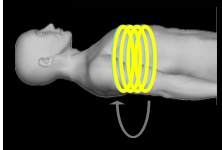
Technical Implementations of DECT



Slow kVp Switching
Inter-scan delay =
scan time + table move time

Fast kVp Switching

Low kVp
High kVp

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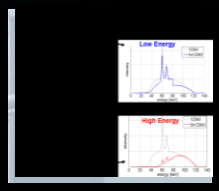
Technical Implementations of DECT

Dual Source



Use twin beam filters

Low kVp
High kVp

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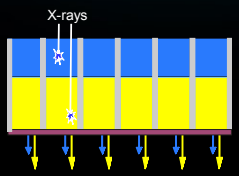
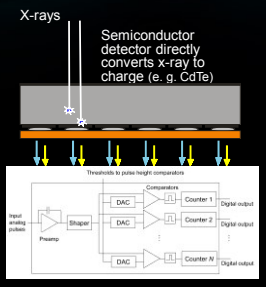
Technical Implementations of DECT



Dual Layer
"Sandwich" Detectors



Photon Counting Detector

C. McCollough, S Leng, L Yu, JG Fletcher. *Dual- and Multi-Energy CT: Principles, Technical Approaches, and Clinical Applications.* Radiology, 2015

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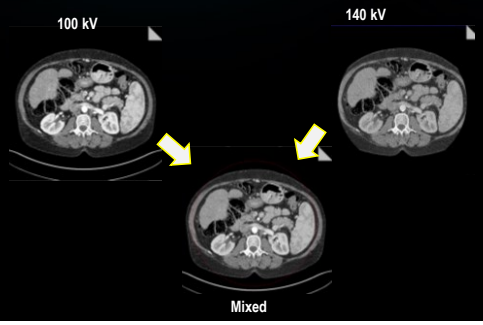
DECT Image Type and Processing Algorithms



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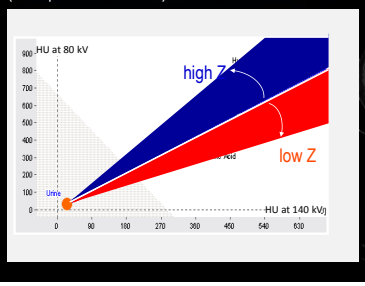
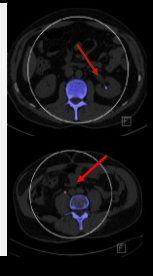
Material Differentiation

- Differentiate two different type of materials (no quantification)





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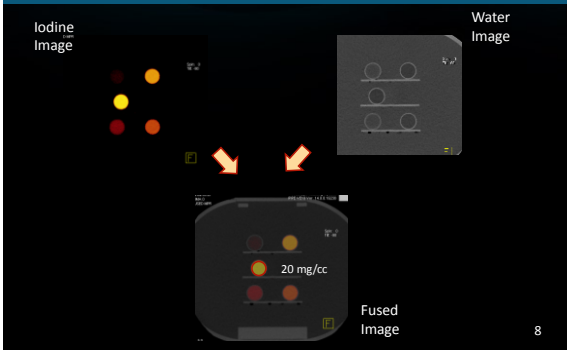
Iodine and Water Quantification



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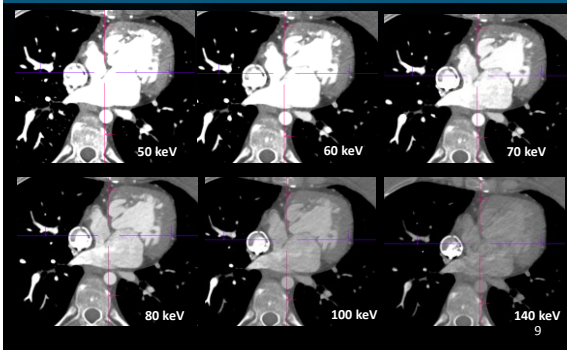
Virtual Monoenergetic Images



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Clinical Applications

- Renal stone differentiation
- Bone/Plaque removal in CTA
- Virtual noncontrast (VNC) image from contrast scans
- Bone bruise (VNCa)
- Lung perfusion
- Cardiac perfusion (blood pool)
- Gout detection and quantification
- Tumor treatment response assessment
- …

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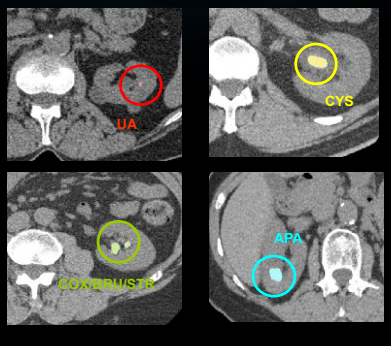
Renal Stone Differentiation



Qu et al, AJR, 2011

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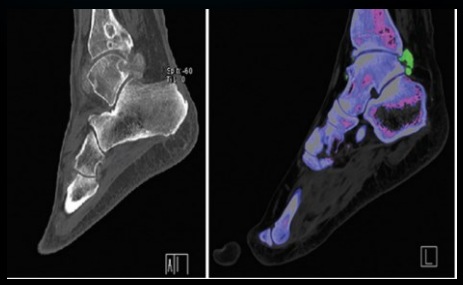
Material Differentiation - Gout



Glazebrook et al, Radiology, 2011

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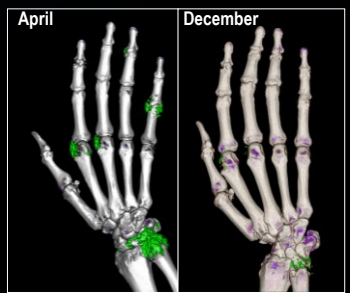
Material Differentiation - Gout

- All accurate assessment of disease burden to monitoring treatment effectiveness



90% reduction in volume of uric acid crystals over 8 months after receiving multiple infusions of rasburicase.

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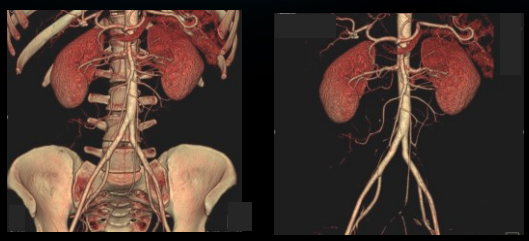
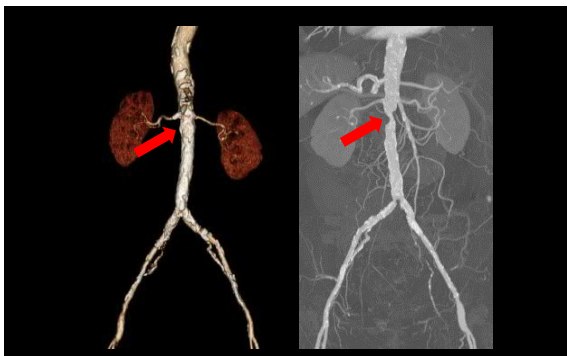
Bone Removal

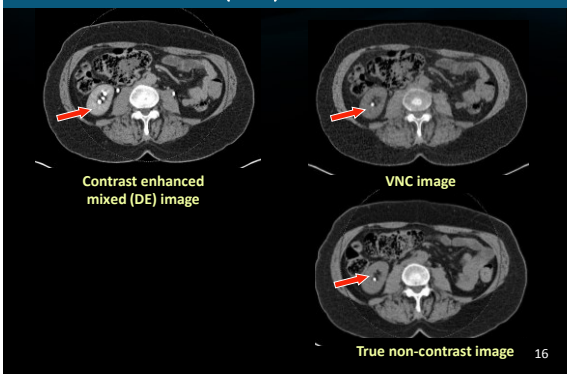


Courtesy Terri Vrtiska, MD



AP images
Routine volume rendered 3D images obscured the stenosis (left)
The high grade stenosis is easily depicted with DECT subtraction (right)

Virtual non-contrast (VNC)



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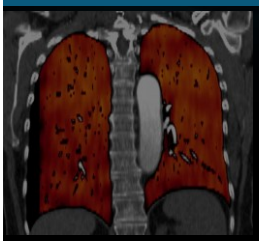
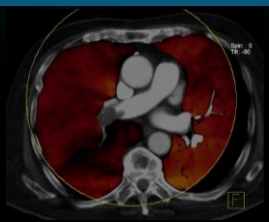
Lung perfusion



Normal: homogeneous iodine map



Patient with deep venous thrombosis developing severe dyspnea. Massive PE with occlusion of the right pulmonary artery. DE perfusion map shows an extensive perfusion defect in the right lower lobe

Thieme et al, Seminar in Ultrasound, CT and MRI, 2010

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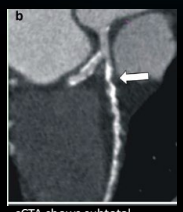
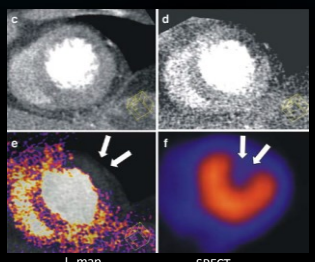
DE Cardiac



cCTA shows subtotal occlusion (arrows) w/ calcified plaque



I_2 map SPECT

Ruzsics et al, Dual-energy CT of the heart for diagnosing coronary artery stenosis and myocardial ischemia-initial experience. Eur Rad. 2008

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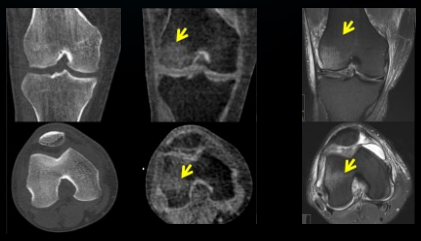
Virtual non-calcium Image



SECT DECT - VNCa MRI

S. Ai et al, *Use of dual-energy CT and virtual non-calcium techniques to evaluate post-traumatic bone bruises in knees in the subacute setting.* Skeletal Radiology; 2014

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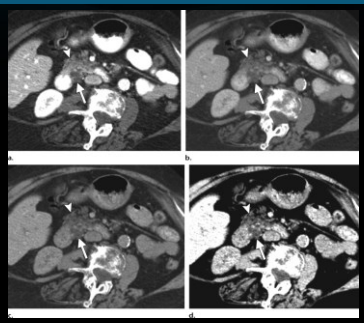
Monoenergetic Image



40 keV

85 keV

120 keV

140 keV (narrower window setting)

Image window was adjusted individually.

Silva et al, Radiographics 2011

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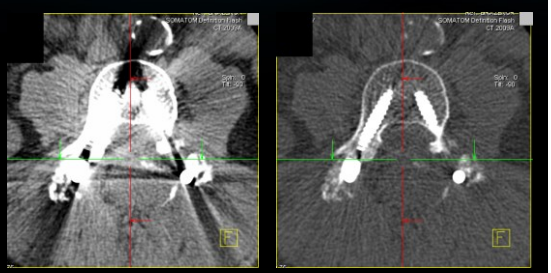
Metal Artifacts Reduction



Standard Image

Monoenergetic Image (105 keV)

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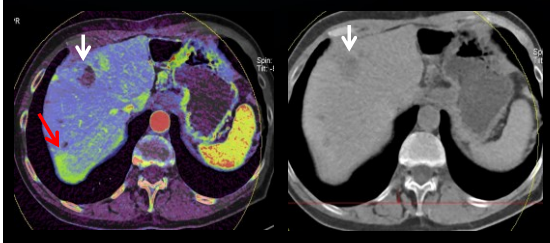
Dual Energy in Oncology

Iodine Maps - Characterization



Iodine Color Map – late arterial phase

VNC – late arterial phase

Courtesy of Dr. Joel G. Fletcher

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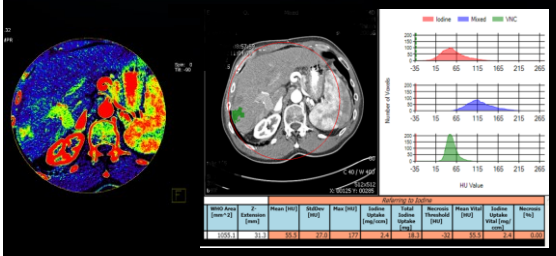
Dual Energy in Oncology

Iodine Quantitation & Response to Rx



Courtesy of Dr. Joel G. Fletcher

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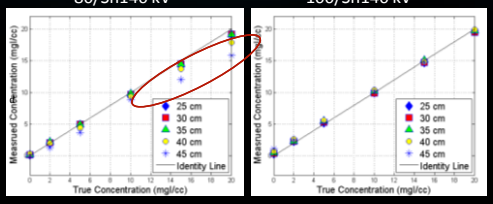
Iodine Quantification – 2nd Generation DSDE

80/Sn140 kV

100/Sn140 kV



Scanner Model	DE Mode	25 cm	30 cm	35 cm	40 cm	45 cm	All Sizes
2nd Gen. DS	80/Sn140kV	0.4	0.3	0.4	0.8	1.7	0.7
	100/Sn140kV	0.3	0.3	0.3	0.5	0.5	0.4

Leng et al, Phys. Med. Bio., In Press

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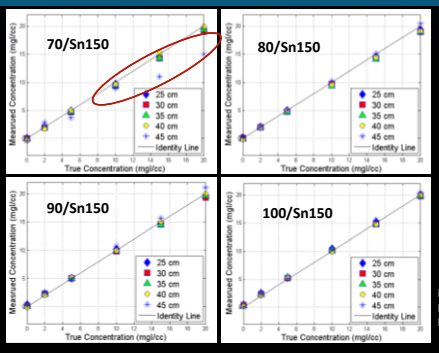
Iodine Quantification – 3rd Generation DSDE



Leng et al, Phys. Med. Bio., In Press

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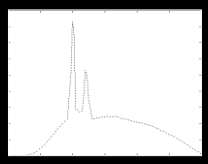
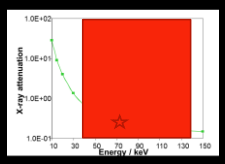
Energy Selective Images

- CT data acquisition:
  - Polyenergetic beam
  - CT number represents effective attenuation
- Virtual monoenergetic (monochromatic) images (VMI):
  - mimicking image acquired with a monoenergetic beam
  - CT number: attenuation at a certain keV.





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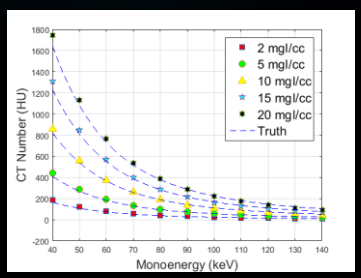
VMI CT Number Accuracy



Leng et al, Phys. Med. Bio., In Press

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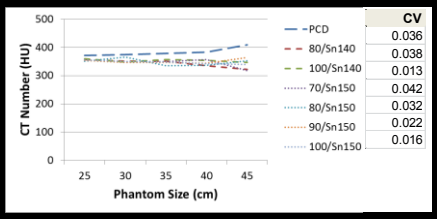
CT number stability

- Across scanner models and phantom sizes
- VMI CT numbers for 10 mgI/cc at 60 keV



	CV
PCD	0.036
80/Sn140	0.038
100/Sn140	0.013
70/Sn150	0.042
80/Sn150	0.032
90/Sn150	0.022
100/Sn150	0.016

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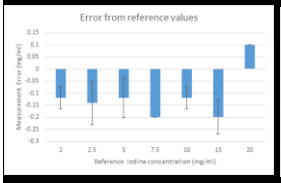
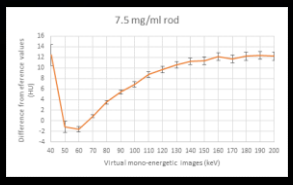
Iodine Quantification and CMI CT Number Accuracy

Philips iQon scanner





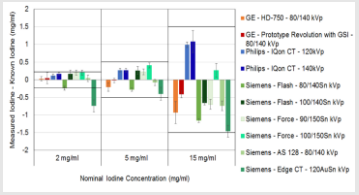
Courtesy of Dr. Xinhui Duan, UT South Western

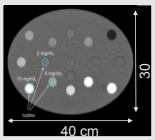
THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center

Iodine Quantification

- Error in iodine measurement generally within 10% across vendors (horizontal lines)
  - Split-filter system within 10% of nominal value post-calibration

Jacobsen, et al. Inter-manufacturer Comparison of Dual-Energy Computed Tomography Iodine Quantification and Monochromatic Attenuation: A Phantom Study. Radiology. Accepted pending revisions. July 2017.





Effect of Calibration on Split-Filter System:

Nominal Iodine Concentration	Default Settings [mg/mL]	Calibrated Settings [mg/mL]
2 mg/mL	1.3 ± 0.2	2.0 ± 0.2
5 mg/mL	4.6 ± 0.2	5.4 ± 0.2
15 mg/mL	13.5 ± 0.2	14.2 ± 0.2

Courtesy of Dr. Dianna Cody

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Radiation Dose

- Dual-energy scans don't need to increase dose
  - Dose distributed between low/high energy acquisitions, each has a fraction of the total dose
  - Mixed images use all photons (dose)

100 kV 140 kV Mixed

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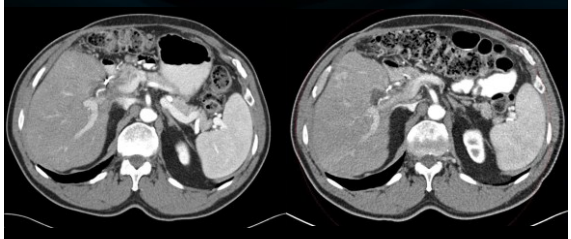

Single Energy (120 kV)
March 2009
CTDIvol: 18.65 mGy

Indication: HCC
35 – 36 cm
lateral width

Dual Energy Mixed
April 2009
CTDIvol: 15.59 mGy

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Radiation Dose

- Dual-energy scans don't need to increase dose
  - Dose distributed between low/high energy acquisitions
  - Mixed images
  - VMI
  - Energy domain noise reduction

50 keV 70 keV 100 keV

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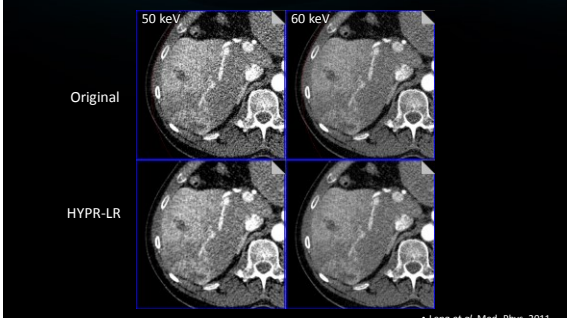
Energy Domain Noise Reduction



- Leng *et al*, Med. Phys. 2011
- Leng *et al*, Radiology, 2015

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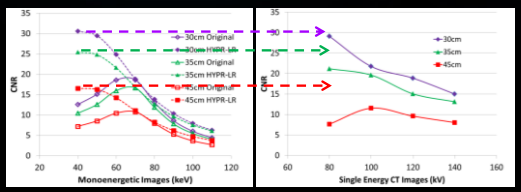
Energy Domain Noise Reduction



DECT VMI SECT

- Leng *et al*, Med. Phys. 2011
- Leng *et al*, Radiology, 2015

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Summary

- Multiple technical approaches have been implemented to perform DECT
- Different types of images can be generated by DECT
  - Low/high/mixed images
  - Material specific images
  - Energy selective images (VMI)
- Wide range of clinical applications
- Considerations in clinical trial
  - Accurate iodine quantification
  - Accurate and stable VMI CT number
  - Radiation dose comparable to SECT
  - Impact of patient side on DE mode selection


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