Multi-energy CT:
Extending the Power of Clinical CT

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Financial Disclosures

- Consultant, Bracco Diagnostics

Learning Objectives

- Types of DE scanners and comparative workflows
- Clinical Utilization
  – High Contrast Imaging
  – Material Decomposition
- Photon Counting CT
- DECT in Radiation Therapy

DECT is *not* a new idea

DETERMINATION OF ATOMIC NUMBER OF MATERIAL
It is possible to use the machine for determining approximately the atomic number of the material within the slice. Two pictures are taken of the same slice, one at 100 kV and the other at 140 kV. If the scale of one picture is adjusted so that the values of normal tissue are the same on both pictures, then

1973, *British Journal of Radiology*, 46, 1016–1022

Computerized transverse axial scanning (tomography): Part I. Description of system

G. N. Hounsfield
Central Research Laboratories of EMI Limited, Hayes, Middlesex

(*Received February, 1973 and in revised form July, 1973*)

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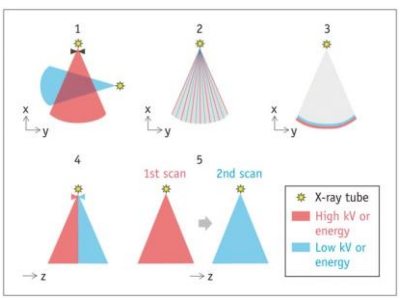
5 configurations of commercial DECT



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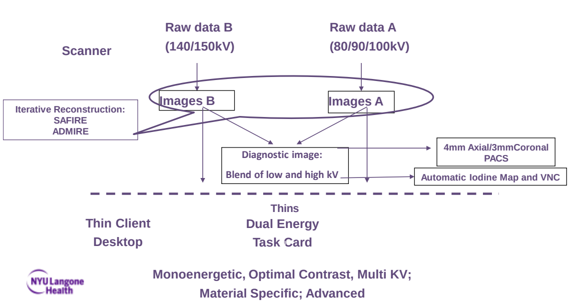
Goo HW et al: Korean J Radiol.2017

Dual Source Dual Energy CT: Work Flow NYU



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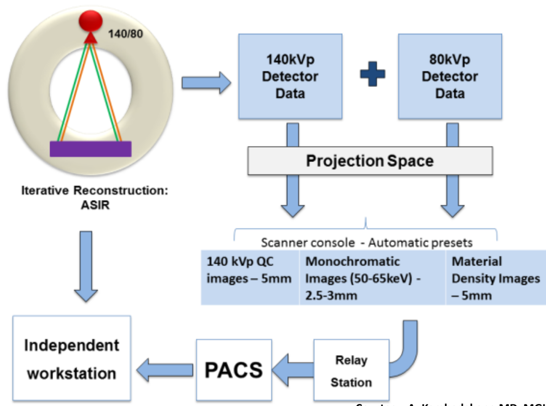
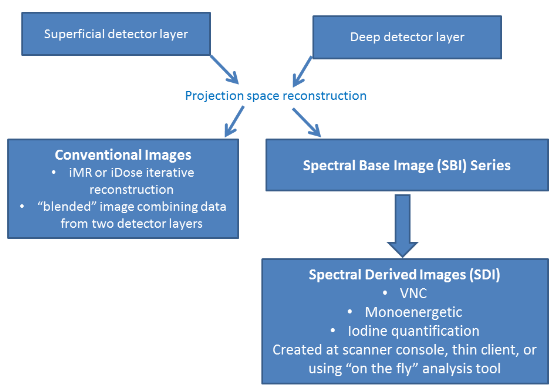


Courtesy: A. Kambadakone MD, MGH



Courtesy: L. Anthanankrishnan, MD, UT Southwestern

Pros and Cons of DE Approaches

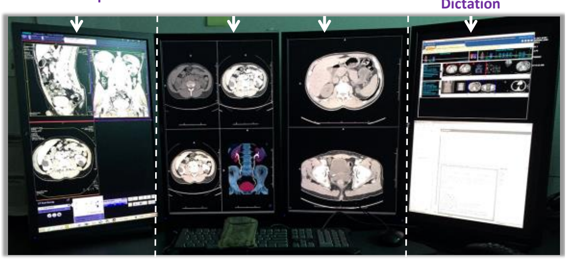
Fast kV switching	Dual-layer detector	Dual-source
Simultaneous DE acquisition	Simultaneous DE acquisition	Simultaneous DE acquisition
Full dual-energy FOV	Full dual-energy FOV	Limited DE FOV
DE processing in both raw data and image domains	DE processing in both raw data and image domains	DE processing only in image domain due to 90° offset between tubes
No independent mA for high and low kV	No independent mA for high and low kV	Independent mA for both high and low kV
Not enough power for low kV images	Not enough power for low kV images	2 tubes: More power for low kV images
Limited spectral separation	Poor spectral separation	Better spectral separation due to tin filter

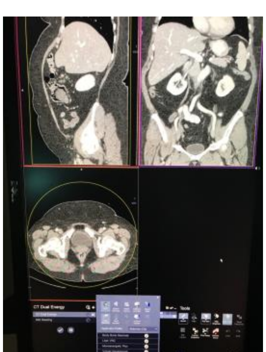
Dual Source Dual Energy Workflow-NYU

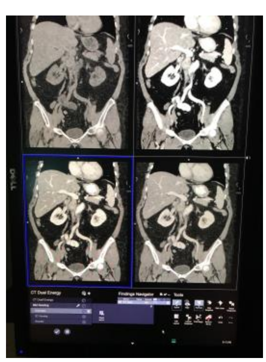
- Workflow
  - How we view DE image data
  - DE analysis-PACS interface
  - Image types available

PACS Reading

DE Workspace | Current | Priors | PACS "Folder"/ Dictation







Question 1

- Which of the following statements concerning DECT acquisition is TRUE

A. All machines are calibrated such that there is no ability to vary high and low energy kVp

B. All scanners reconstruct images in projection space

C. High and low energy images may be blended in to create a final image that simulates a standard single energy 120 kVp CT image

D. DECT images cannot be acquired with isotropic voxels

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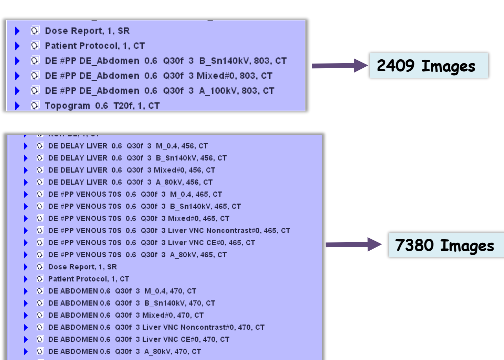

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Image viewing/archiving

What we Do

- 4mm axial/3mm coronal on PACS
  - Image interpretation
  - Long term Archive
- DE data
  - View PRN. Selected rendered images or series exported to PACS
  - A and B tube or Au/Sn thin sections sent to a long term archive from SCANNER

What we DON'T do

- We do NOT send A tube/B tube/ mixed *thin* sections to PACS
  - Nor expect radiologist to view
- We do NOT routinely look at these images
- We do NOT routinely archive mono+, optimum contrast, low kV, VNC etc.

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Clinical Uses of DE Acquisitions in Abdominal Imaging

- Improve Inherent Image Contrast
  - Low kV images
  - Optimal Contrast
  - Monoenergetic Imaging
- Precision CT numbers
  - Monoenergetic Imaging
- Material Decomposition
  - Calcium
    - Bone Removal
  - Iodine
    - VNC
- Reducing Radiation Dose
- Iodine Quantification

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Improved Inherent Image Contrast

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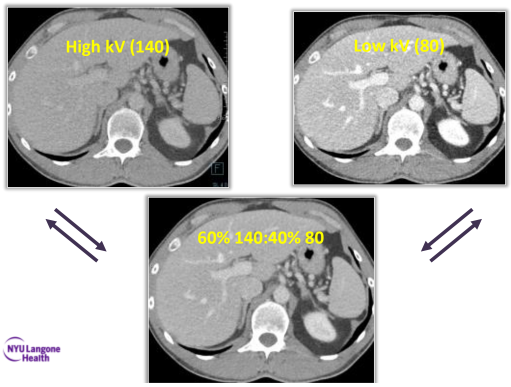
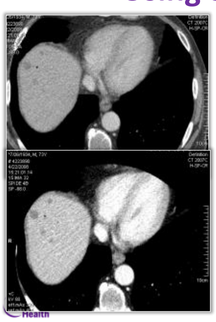


Using 80 kVp Image



- Iodine is more conspicuous
- Higher Noise level

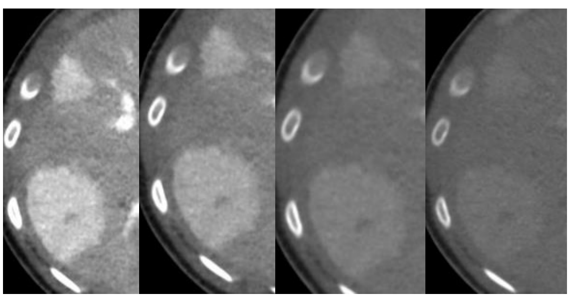
Monoenergetic Imaging

- Improved image contrast
  - Greater Iodine conspicuity* than low kV image
  - “Salvaging CTA”
  - Lower IV contrast Dose
- Metal artifact reduction

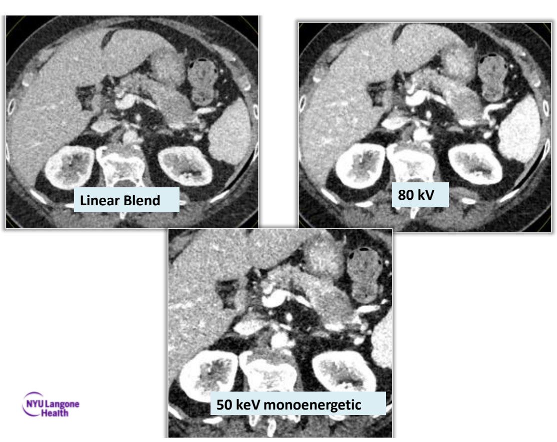
*Dependent on setting

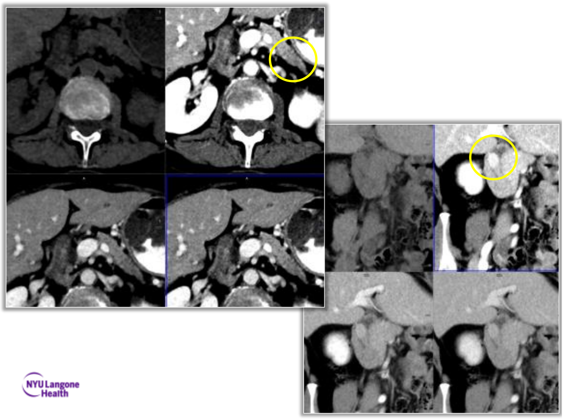
Monoenergetic Imaging

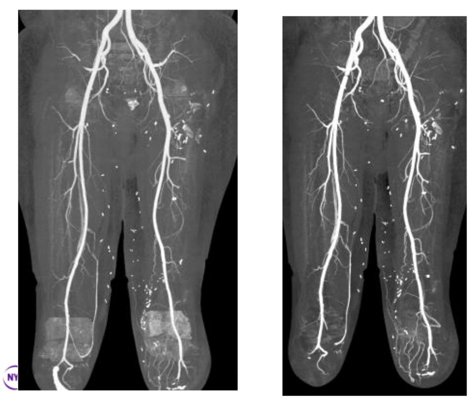
- **50 keV significant iodine visualization with acceptable noise**
- 70 keV close to 100 kVp conventional CT
- >120 keV for metal artifact reduction



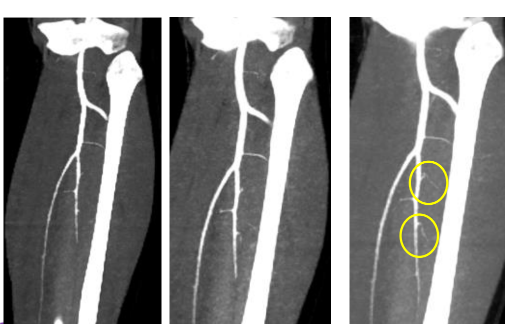
40 keV 50 keV 70 keV 90 keV

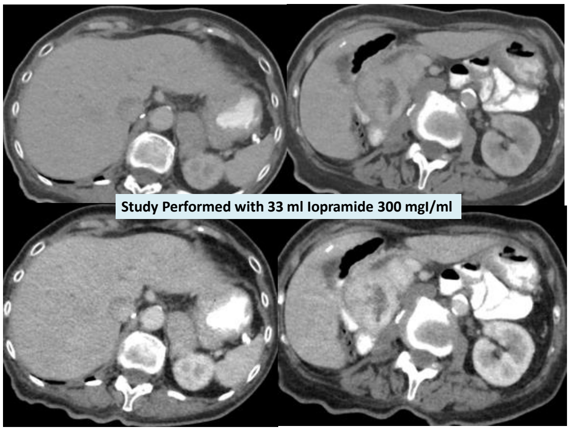


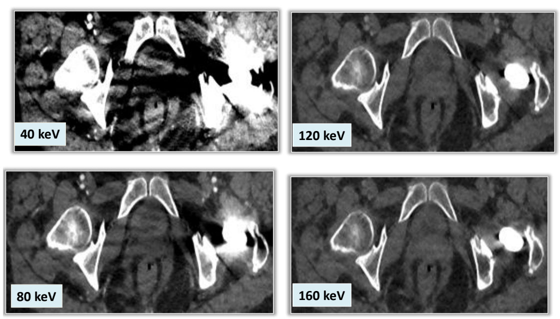




Mixed 150:80 kV 50% | 80 kV | 50 keV mono+







Question 2

- Concerning “monoenergetic” imaging, which of the following statements is FALSE

  A. <50 keV images can help reduce the amount of administered IV contrast due to increased conspicuity of iodine

  B. >100 keV images are useful for metal artifact reduction

  C. Monoenergetic acquisitions have been shown to minimize pseudoenhancement of lesions

  D. Hounsfield units are unchanged when comparing images at any monoenergetic setting.

Question 2

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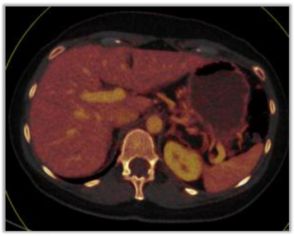
3-Material Decomposition

- Virtual Non contrast Imaging
  - Eliminating acquisitions
- Bone removal
- Characterization of renal calculi

Material Specific Decomposition(s)

- Native image composed of "3" materials
- Two are fixed, 1 variable

Material Specific Decomposition(s)



- Map the variable
  - Iodine Map

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Material Specific Decomposition(s)

- Remove the variable
  - Virtual Non Contrast (VNC)

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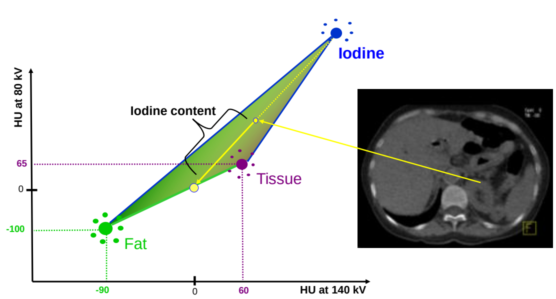

- Removal of iodine from the renal cortex

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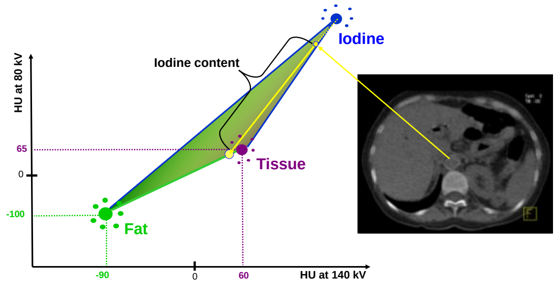
Courtesy: C. Leidecker, PhD, Siemens Medical Systems



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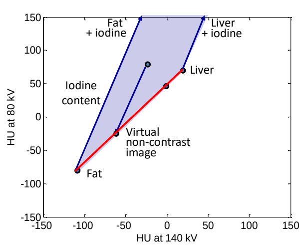
- Removal of iodine from the aorta

Courtesy: C. Leidecker, PhD, Siemens Medical Systems

Three Material Decomposition: Fat/Liver/Iodine



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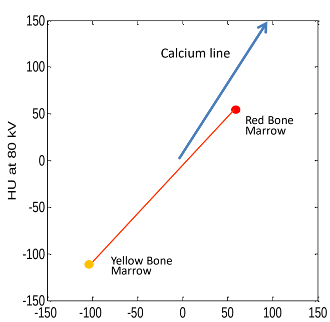
Quantifying: Fat, Liver, and Iodine

Courtesy: Tom O'Donnell, PhD



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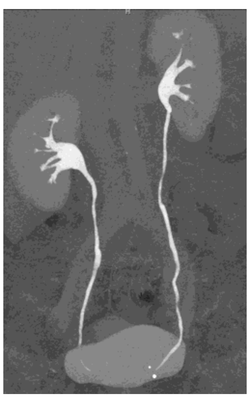
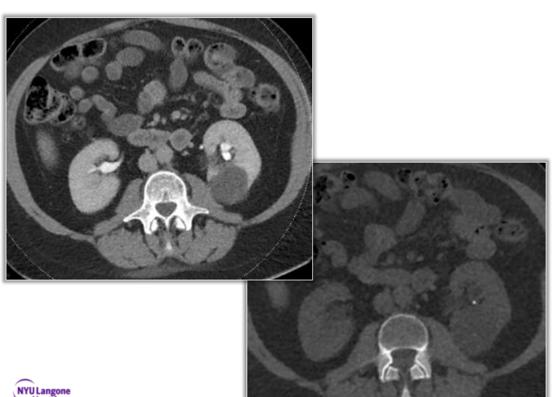
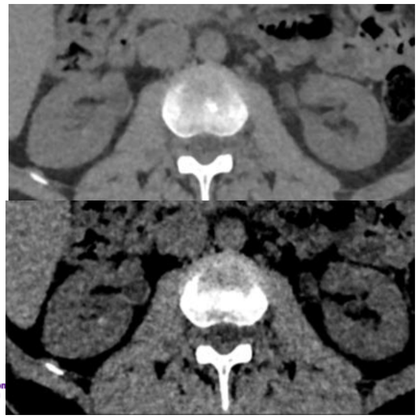
Clinical Utility of Material Specific Imaging
DSDE CT

- Bone Removal
- Calculi
- **Virtual Non-Contrast Image**







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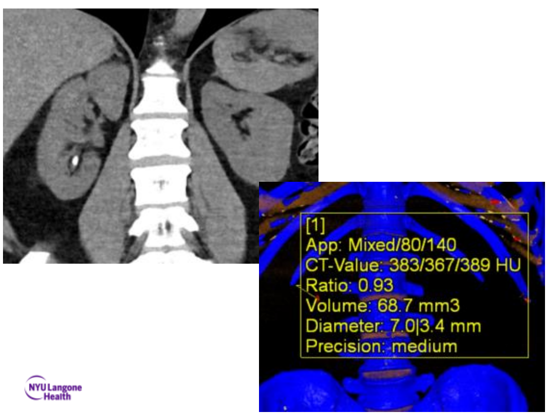

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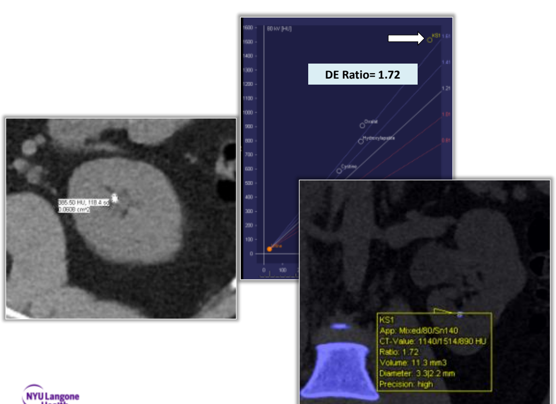

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Original Article

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DOI: 10.1177/0284185114538251
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In vivo characterization of urinary calculi on dual-energy CT: going a step ahead with sub-differentiation of calcium stones

Sudeep Acharya[1], Ankur Goyal[1], Ashu Seith Bhalla[1], Raju Sharma[1], Amlesh Seth[2] and Arun Kumar Gupta[1]

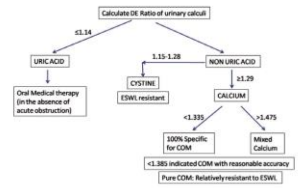
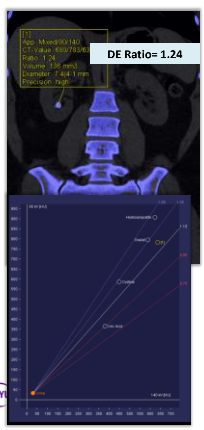
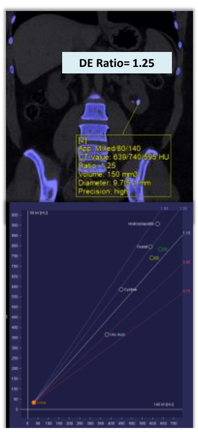


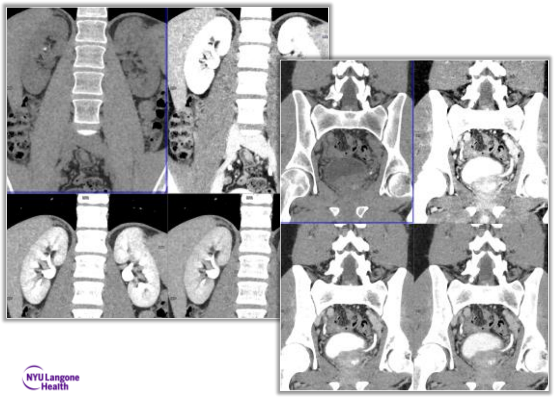
Fig. 6. Working flow chart to detect the composition of urinary calculi with impact on management.

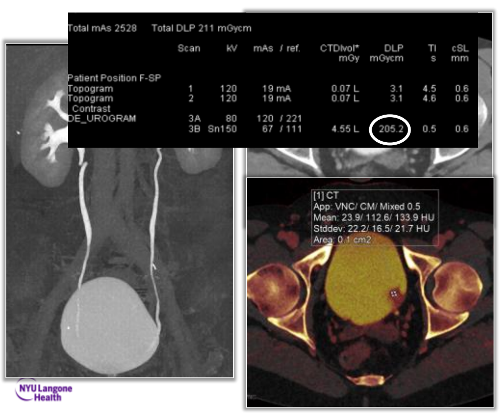




Modified DE CT Urogram

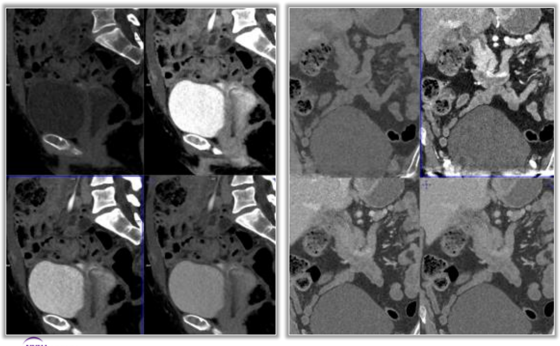
- Indication- microscopic hematuria in patients under 40
- Protocol
  - Single pass CTU at 7 min following 200 cc IV contrast (240 mgI/ml)
  - VNC made from this single acquisition
- Created WITH input from urologists understanding that 2/3 calculi <3mm may be missed

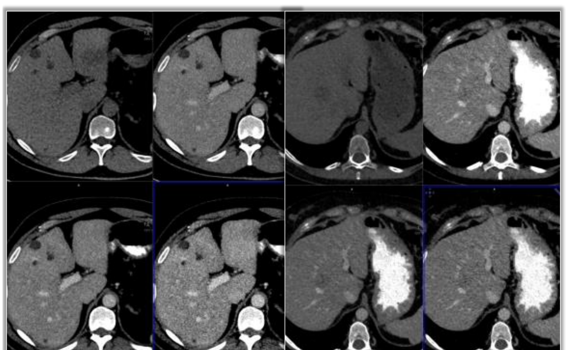


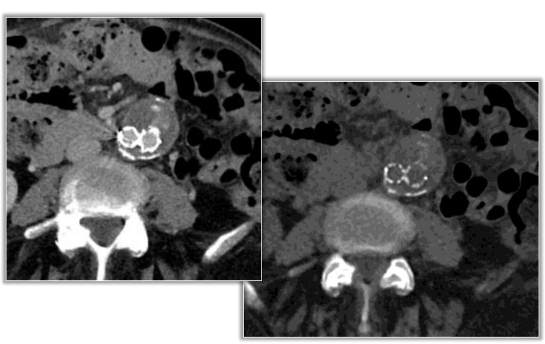


Virtual Non-Contrast Image

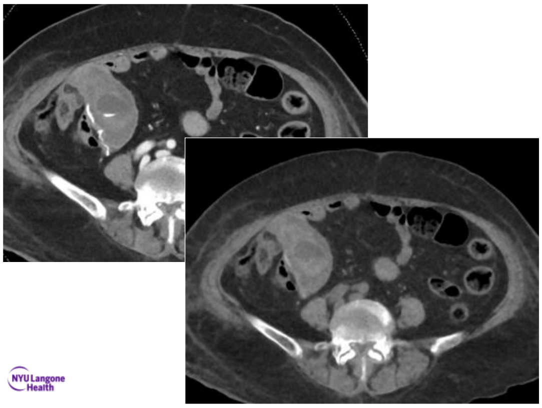
- Respects well established paradigm of recognizing enhancement
  - Can get ROI values
- Iodine Map is equivalent method of acquiring same information
  - Can get quantification of enhancement and mg/I in tissue
- Eliminating acquisitions

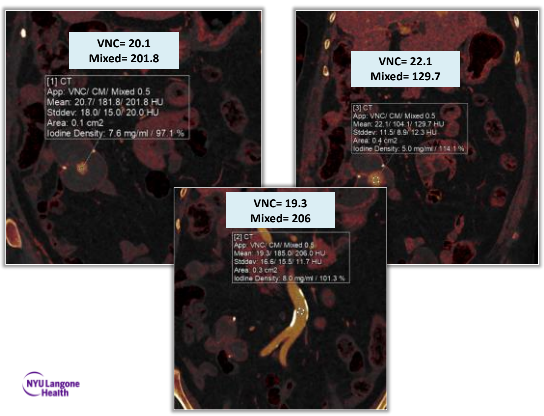


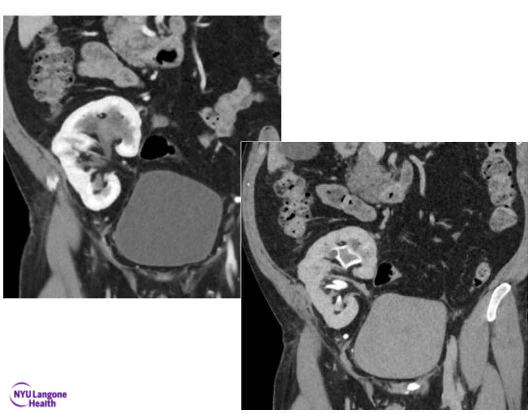


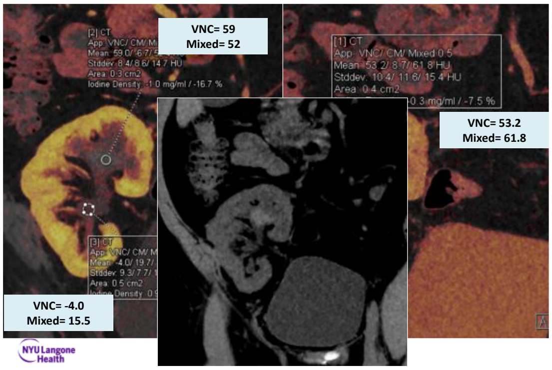


1. Chandarana et al. Radiology:2008
2. Numburi et al. AJR 2010




VNC= 20.1
Mixed= 201.8
[1] CT
App: VNC/ CM/ Mixed 0.5
Mean: 20.7/ 181.8/ 201.8 HU
Stddev: 18.0/ 15.0/ 20.0 HU
Area: 0.1 cm2
Iodine Density: 7.6 mg/ml / 97.1 %
VNC= 22.1
Mixed= 129.7
[3] CT
App: VNC/ CM/ Mixed 0.5
Mean: 22.1/ 104.1/ 129.7 HU
Stddev: 11.5/ 8.9/ 12.3 HU
Area: 0.4 cm2
Iodine Density: 5.0 mg/ml / 114.1 %
VNC= 19.3
Mixed= 206
[2] CT
App: VNC/ CM/ Mixed 0.5
Mean: 19.3/ 185.0/ 206.0 HU
Stddev: 16.6/ 15.5/ 11.7 HU
Area: 0.3 cm2
Iodine Density: 8.0 mg/ml / 101.3 %




[2] CT
Iodine Density: -1.0 mg/ml / -16.7 %
VNC= 59
Mixed= 52
[1] CT
App: VNC/ CM/ Mixed 0.5
Mean: 53.2/ 8.7/ 61.8 HU
Stddev: 10.4/ 11.6/ 15.4 HU
Area: 0.4 cm2
VNC= 53.2
Mixed= 61.8
[3] CT
Area: 0.5 cm2
VNC= -4.0
Mixed= 15.5
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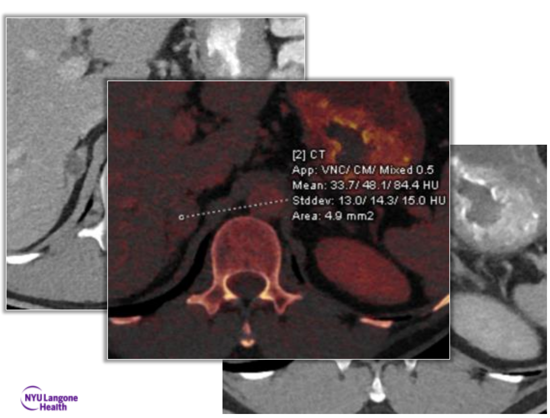
VNC= 8.2
Mixed= 72.7
VNC= 38.2
Mixed= 63.9


[2] CT
App: VNC/ CM/ Mixed 0.5
Mean: 33.7/ 48.1/ 84.4 HU
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Area: 4.9 mm2
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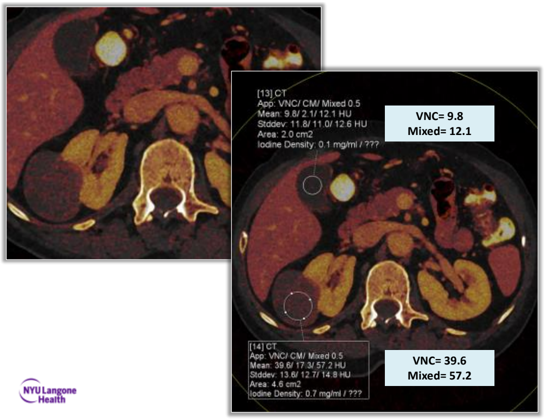

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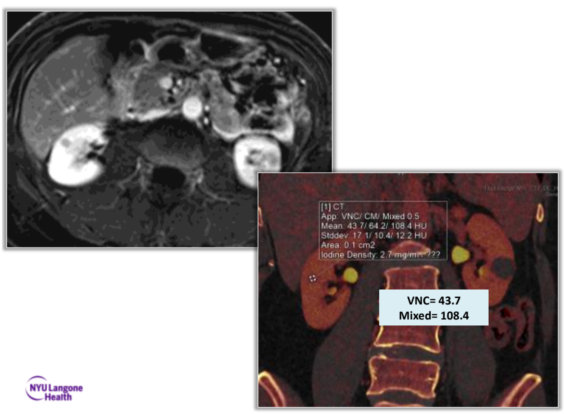

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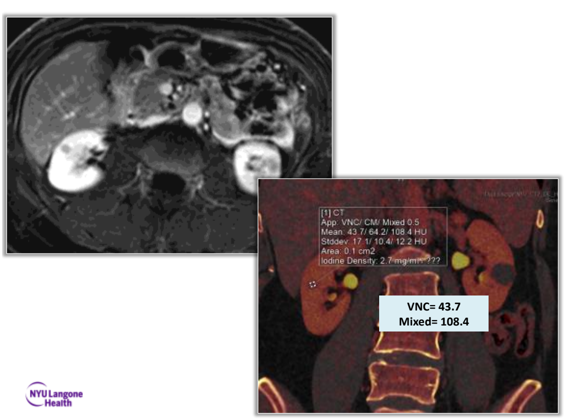

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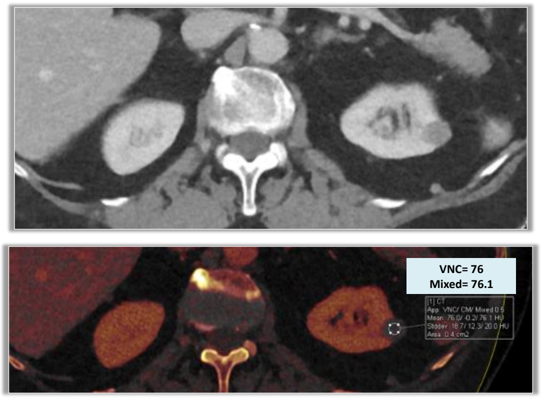
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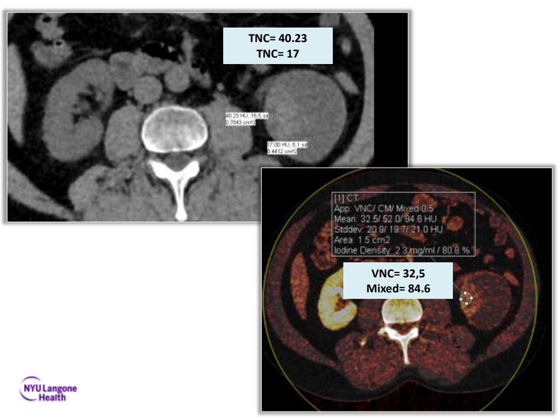
TNC= 40.23
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[1] CT
App: VNC/ CM/ Mixed 0.5
Mean: 32.5/ 52.0/ 84.6 HU
Stddev: 20.9/ 19.7/ 21.0 HU
Area: 1.5 cm2
Iodine Density: 2.3 mg/ml / 80.8 %
VNC= 32,5
Mixed= 84.6
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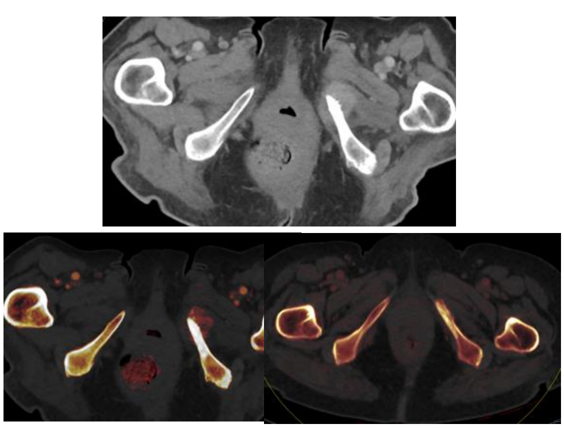

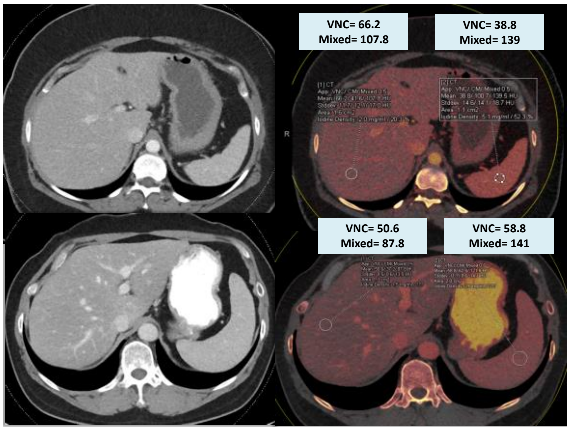
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VNC= 38.8
Mixed= 139
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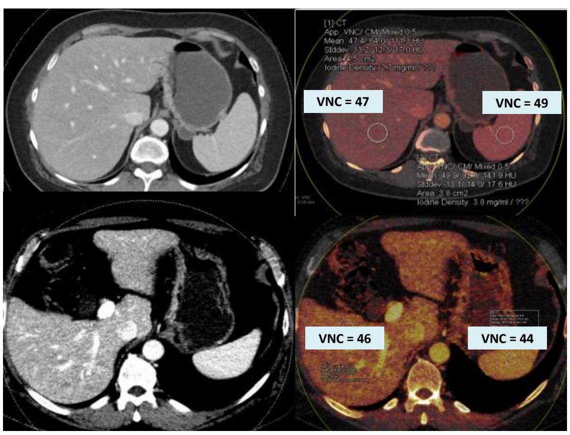
Mixed= 87.8
VNC= 58.8
Mixed= 141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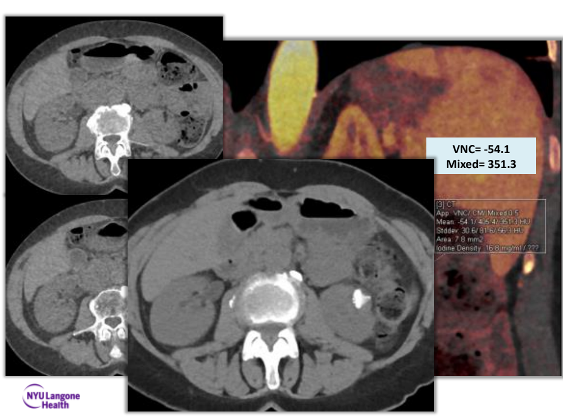
VNC = 46
VNC = 44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Mixed= 351.3
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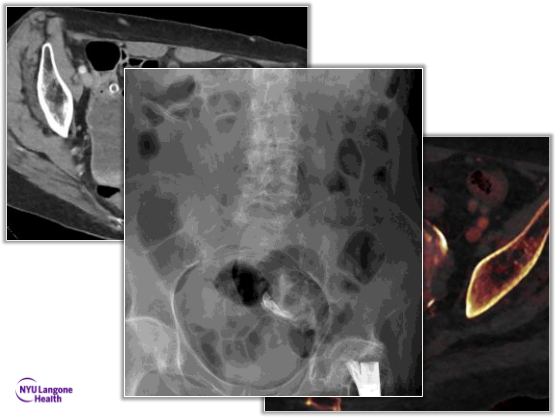

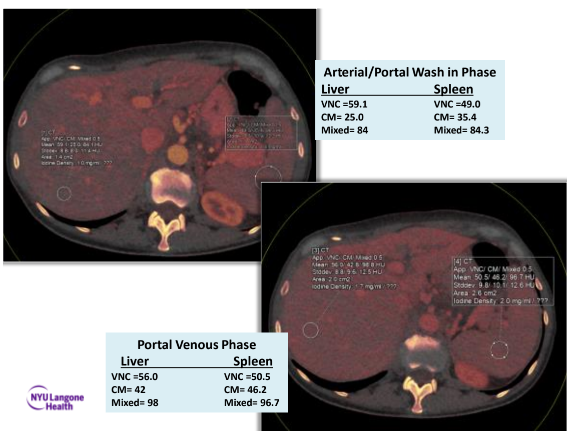

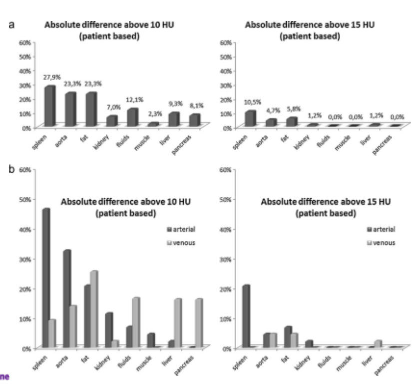

Toepker M. Eur J. Radiol: 2012

Attenuation on TNC and VNC with 3rd Generation DECT

Durieux P. et al AJR 2018;210:1042-1058

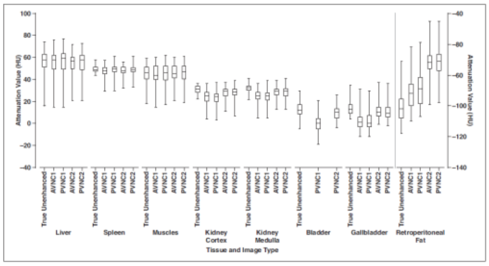

Fig. 3—Box-and-whisker plots of distribution of attenuation values measured on true unenhanced images and virtual unenhanced dual-energy CT images reconstructed with Liver VNC dual-energy algorithm (Siemens Healthcare) in arterial and portal phases (AVNC1 and PVNC1, respectively) and with Virtual Unenhanced dual-energy algorithm (Siemens Healthcare) in arterial and portal phases (AVNC2 and PVNC2, respectively), as stratified per tissue. Boxes denote interquartile interval, horizontal lines within boxes denote median values, and whiskers denote range. Vertical gray line denotes separation between graphs with different *y*-axes.

Question 3

- Concerning virtual non-contrast images derived from DECT data, which of the following statements is true?

A. VNC Hounsfield unit (HU) values are reliably within 5 HU of true non-contrast (TNC) images

B. VNC HU are relatively independent of the amount of the iodine concentration in a given contrast enhanced ROI

C. VNC HU can be directly calculated from rapid kV switching DE scanners

D. VNC HU are less noisy than TNC images

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Question 3

- Concerning virtual non-contrast images derived from DECT data, which of the following statements is TRUE?

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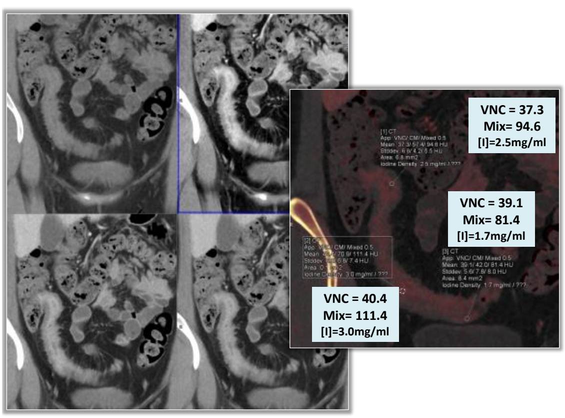
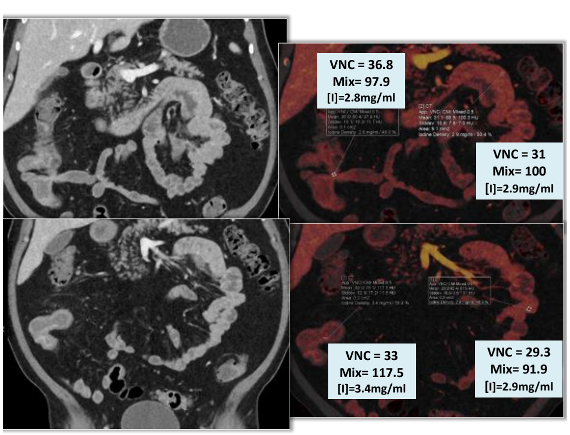
Iodine Quantification

- Assessing tumor (neo)vascular "burden" before and during therapy
- Inflammation/repair in Crohn disease





Radiation Considerations

ORIGINAL ARTICLE

Dual Energy CT of the Chest

How About the Dose?

Jan C. Schenzle, Wieland H. Sommer, MD,* Klement Neumaier,† Gisela Michalski,† Ursula Lechel, MS,† Konstantin Nikolaou, MD,* Christoph R. Becker, MD,* Maximilian F. Reiser, MD,* and Thorsten R. C. Johnson, MD**

Conclusion: Dual Energy CT is feasible without additional dose. There is no significant difference in image noise, while CNR can be doubled with optimized dual energy CT reconstructions. A restriction in collimation is required for dose-neutrality at 140/80 kVp, whereas this is not necessary at 140 Sn/100 kVp. Thus, CT can be performed routinely in Dual Energy mode without additional dose or compromises in image quality.

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JC Schenzle et. al. Investigative Radiology • Volume 45, Number 6, June 2010

Perceived Impediments to Routine Dual Energy Scanning

- Images are not as good
- Slows throughput in busy practice
- Too many images on PACS
  - Too much time to read
- Lack of workstation familiarity
- No “trust” in quantitative data
- Increased Radiation

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Our Practice

- ~130 outpatient CASES per day on 2 machines,
  - Scanning hours 7:30 AM-7PM
- All C+ Abd/Pel, Chest and C- renal calculi studies on are done with DE

Date	CR	CT	MR	PT	RF	US	GRAND TOTAL
2017-06-01	122	126	149	3	9	107	**516**
2017-06-02	83	110	132	5	15	116	**461**
2017-06-03	3	62	123	0	0	18	**206**
2017-06-04	0	0	107	0	0	0	**107**
2017-06-05	122	140	137	4	24	111	**538**
2017-06-06	112	131	151	4	22	123	**543**
2017-06-07	113	130	140	3	20	118	**524**
2017-06-08	114	124	144	2	25	108	**517**
2017-06-09	106	120	137	7	20	123	**513**
2017-06-10	9	56	108	0	0	29	**202**
2017-06-11	0	0	96	0	0	0	**96**
2017-06-12	110	131	146	4	17	108	**516**
2017-06-13	92	139	135	4	20	121	**511**
2017-06-14	109	129	147	3	19	128	**535**
2017-06-15	121	141	145	2	23	119	**551**
2017-06-16	7	16	13	0	3	10	**49**
GRAND TOTAL	**1,22[illegible]**	**1,555**	**2,010**	**41**	**217**	**1,339**	**6,385**

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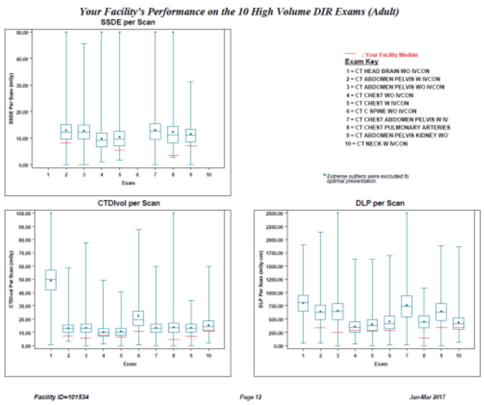


Photon Counting Multi-Energy CT

Following slides courtesy:

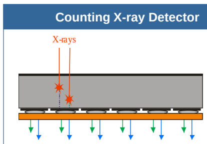
Shuai Leng, PhD. Mayo Rochester

Siemens Medical Solutions

NYU Langone Health

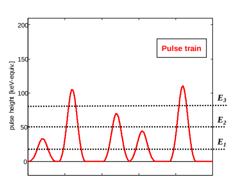
Counting Detector Technology

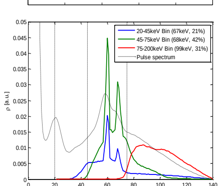
Counting X-ray Detector



- Semiconductor as direct X-ray converter
- Photoelectron creates electron-hole pairs
- Electrons induce short pulses on pads
- Pulses are counted individually with counter thresholds on different energy levels

→ **multiple signals with spectral sensitivity**





→ One scan yields multiple spectral datasets

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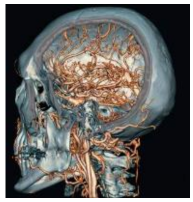
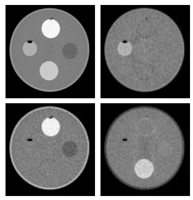
- **Enables "Multi-Energy Anytime"**
  - Single-kVp Multi-Energy CT
  - Spectral information at full FOV
  - CT becomes quantitative modality
  - Three-material decomposition by K-edge imaging
- **Opens Fields of New Clinical Research**
  - Search of novel, photon counting specific CT applications
- **Note: Quality of Two-Material Separation**
  - **Photon-Counting as good as kV-Switching**
  - **Photon-Counting does not outperform Dual-Source**

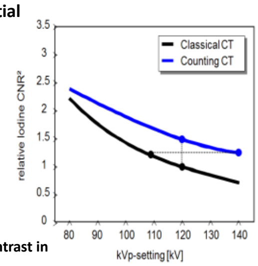




Counting Technology: What is the Potential?

- **Further Dose or CM Saving Potential**
  - More iodine contrast
  - Less image noise (better MTF)

  → Up to 46% more iodine CNR²
  (or 32% less dose or 20% less CM)
- **"One-Stop Shop" Examinations?**
  - Routinely perform scans at 140 kV
    - Same CNR as classical CT at 105 kV
    - Less scan protocols
    - Retrospective Multi-Energy analysis
- **Note:**
  - **No significant boost of soft tissue contrast in native scans (e.g. grey-white matter)**



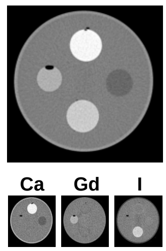
Counting Technology: What is the Potential?

- **Beam-Hardening Artifact Reduction**
  - Spectral information for refined artifact reduction
- **High-Resolution CT Data**
  - Significantly better spatial resolution in sub-pixel mode, approaching the spectral resolution of a conventional x-ray / DSA
  - Noise reduction in particular with sharp kernels
  - UHR modes at full dose usage
- **Better IQ in Ultra-Low-Dose and Obese Scans**
  - Less noise in low-signal scans → better IQ, less dose
  - Better stabilization of CT-values
  - Further suppression of streak artifacts

Counting Technology: What is the Potential?

Multi-Energy CT

- **Single-kV Single-Scan Multi-Energy CT**
  - **Dual-Energy performance similar to Dual-Source CT**
  - Multi-Energy to separate more than two materials
- **Use well-established Dual-Energy Applications**
- **Explore novel Multi-Energy Applications**:
  - Separate and quantify multiple contrast media?
  - Entirely new fields of clinical research?



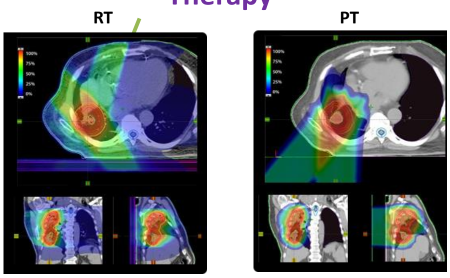
Dual Energy CT in Radiation Therapy

Following slides courtesy:

Tom O'Donnell PhD

Siemens Healthineers USA

Tissue Characterization for Proton Therapy



Range uncertainty 3-4mm - BIG Problem

http://www.iba-protontherapy.com/why-proton-therapy

Attenuation Coefficient of an arbitrary material
at a specific energy and a fixed density:

Attenuation of any material = a_1 Compton Scatter + a_2 Photoelectric Effect

(density) *(atomic number)*

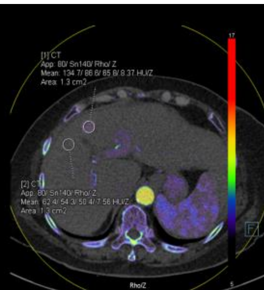
These are characteristic of the material

2 Equations and 2 unknowns:

Attenuation on 80kVp scan = a_1 Compton Scatter on 80kVp scan + a_2 Photo Electric on 80kVp scan

Attenuation on 140kVp scan = a_1 Compton Scatter on 140kVp scan + a_2 Photo Electric on 140kVp scan

syngo.CT DE with Rho/Z* TwinBeam Dual Energy



- Enables to calculate electron density and effective Z maps in one examination
- FoV: 50cm
- Helps to differentiate and characterize different tissues in the body
- Ideal for research oriented customers:
  - **PT: enables a novel way of calculating stopping power ratio (SPR) more precisely**

Courtesy of Universitätsklinikum Erlangen, Radiology Department
*TwinBeam postprocessing software is under development. Not available for sale in the U.S

Page 93 October 2015

Robust quantitative contrast-enhanced dual-energy CT for radiotherapy applications

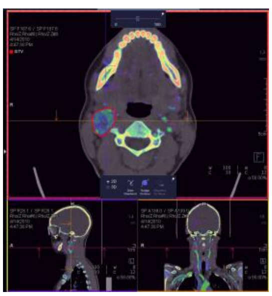
Andréanne Lapointe, and Arthur Lalonde
Département de physique, Université de Montréal, 2900 boulevard Édouard-Montpetit, Montréal, QC H3T 1J4, Canada

Houda Bahig
Département de radio-oncologie, Centre hospitalier de l'Université de Montréal (CHUM), 1000 rue Saint-Denis, Montréal, Québec, H2X 0C1, Canada
Centre de recherche du Centre hospitalier de l'Université de Montréal, 900 Rue Saint-Denis, Montréal, QC H2X 0A9, Canada

Jean-François Carrier, Stéphane Bedwani, and Hugo Bouchard[a)]
Département de physique, Université de Montréal, 2900 boulevard Édouard-Montpetit, Montréal, QC H3T 1J4, Canada
Département de radio-oncologie, Centre hospitalier de l'Université de Montréal (CHUM), 1000 rue Saint-Denis, Montréal, Québec, H2X 0C1, Canada
Centre de recherche du Centre hospitalier de l'Université de Montréal, 900 Rue Saint-Denis, Montréal, QC H2X 0A9, Canada

Conclusion: This study identifies two accurate methods to quantify iodine-based contrast agents and virtual noncontrast composition images with dual-energy CT. One is the two-material decomposition with *a priori* knowledge of the constituent components focused on organ-specific applications, such as kidney or lung function assessment. The other method is the eigentissue decomposition and is useful for general radiotherapy applications, such as treatment planning where accurate dose calculations are needed in the absence of contrast agent.
[https://doi.org/10.1002/mp.12934]

Med. Phys. 45 (7), July 2018



- Interactive adjustment of material decomposition parameters for immediate optimization of the results with ***syngo*.CT DE Rho/Z ***
- Dual Spiral Dual Energy offers better accuracy
- Works where motion is limited
- TBDE will work in regions with excessive motion
- Reduced accuracy
- Not sure if it will let you exceed the SPR you achieve right now

Impediments to DECT for Routine Use in Therapy

- COST of Scanner
- Limited knowledge of how to process DE Data
- Proton Beam therapy has largest use
- Can be performed on ANY scanner
  - Shuttle mode DE
- Would require investment in software to process data