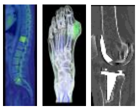
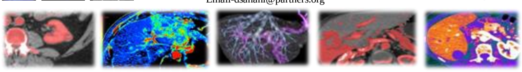
Multi-Energy CT: Technology, Applications and Future Directions



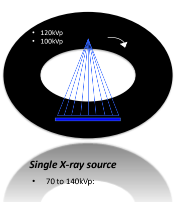
DUSHYANT SAHANI MD.
Director of CT
Associate Professor of Radiology
Massachusetts General Hospital
Harvard Medical School
Email-dsahani@partners.org

AAPM 2017 JUL 30–AUG 3
CONNECTING OUR PATHWAYS, UNIFYING OUR PROFESSION.
59th ANNUAL MEETING & EXHIBITION | DENVER, CO



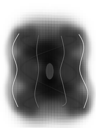
Single Energy CT (SECT)

Lesion to background contrast



Single X-ray source

- 70 to 140kVp:

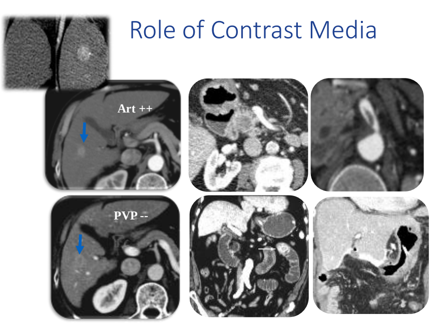


Single sinogram

Image of the scanned object is obtained based on the photon attenuation of its materials

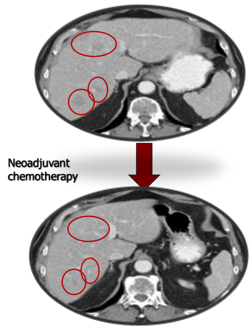
- X-ray attenuation influenced by different materials

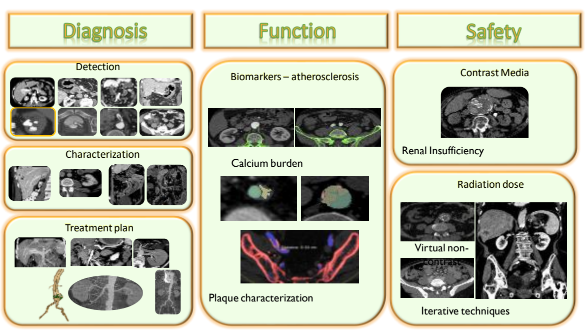
Role of Contrast Media



SECT Challenges

- Small lesion detection and characterization
- Non-contour deforming lesions
- Tissue characterization
  - Inflammation vs tumor
- Peritoneal implants vs Ascites
- Post operative change vs. recurrence
- Response
- Material Separation

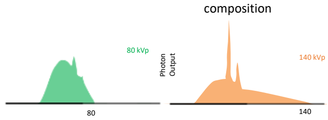




What is the advantage of Dual Energy CT?

DECT provides more information about tissues than SECT

It uses attenuation measurements acquired with different energy spectra, and knowledge of the changes in attenuation between the two spectra is used to assess tissue and material composition

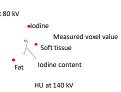


Johnson TRC. Eur Radiology 2007
Stolzmann P. Radiology 2008
Ascenti G, AJR 2011
Megibow A and Sahani DV. AJR 2012
Agrawal M et al. Radiographics 2014

Materials Evaluated On CT

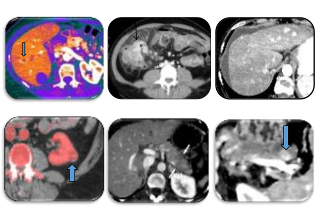
- Iodine- CM enhancement +/-
  - (Z=53)
- Calcium-plaques/stones/bones/le
  - (Z=20)
- Soft tissues
  - hydrogen (Z=1), carbon (Z=6), nitro (Z=7) and oxygen (Z=8)

The principles of DECT is based on varying behavior of materials when exposed to different x-ray photon energies

DECT approach	Material decomposition algorithm		Images generated
dsDECT material specific images Based on image data (after image reconstruction)	*Three material decomposition*		1. Soft tissue 2. Fat 3. Iodine
ssDECT material specific images Based on projection data (before image reconstruction from high and low-energy sinograms)	*Two material decomposition*	Attenuation information of a given material at two different X-ray energies can be mathematically transformed into the amount (concentration) of two material pairs that would be necessary to produce the measured attenuation level.	1. Water 2. Iodine 3. Other base pairs (Iodine: calcium)
	Multi-material decomposition		1. Iodine 2. Fat 2. Bone 3. Fibrosis 5. Soft tissue 6. Blood 7. Air

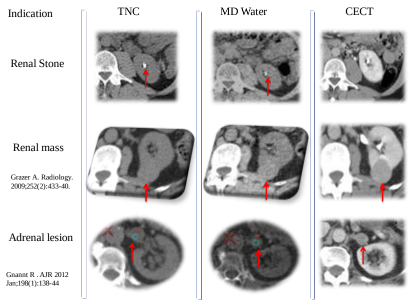
Patino M et al. Radiograhics (in-press)

DECT: MD-Iodine (Water Extraction)

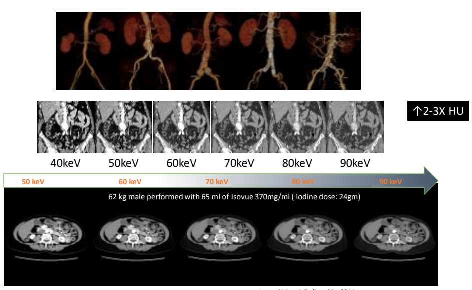


Johnson et al Eur Radiol 2006, Ruzsics et al Circulation 2008
Agrawal M et al. Radiograhics 2014.

DECT: Virtual Unenhanced Images (Iodine Extraction)



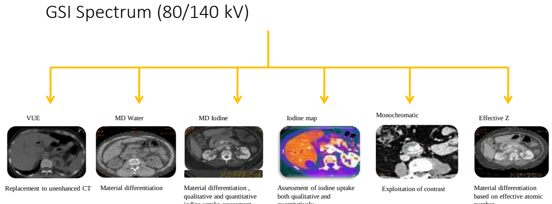
DECT- Virtual Monochromatic Images



Pinho D. Eur Radiol 2011

Agrawal M et al. Radiograhics 2014
Fuentes JM et al. Radiographics 2015

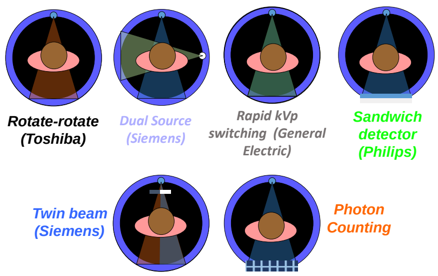
GSI Spectrum (80/140 kV)



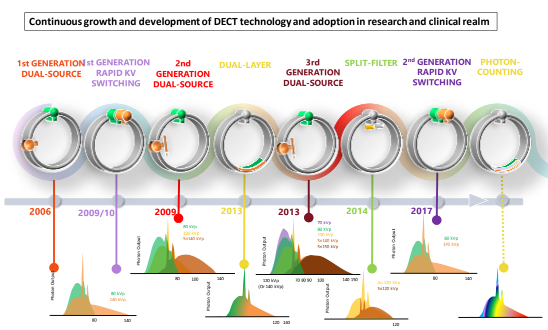
Johnson TRC. Eur Radiology 2007
Stolzmann P. Radiology 2008
Ascenti G, AJR 2011
Megibow A and Sahani DV. AJR 2012
Agrawal M et al. Radiographics 2014

“GSI acquisition is almost similar to SECT but rigorous analysis is performed on the images”

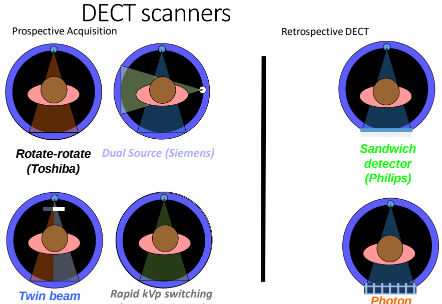
DECT scanners



Courtesy of Ben Yeh, UCSF



DECT scanners



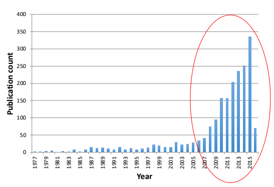
Courtesy of Ben Yeh, UCSF

Potential Benefits of Spectral CT

- Better tissue characterization
  - Easier diagnosis
  - Minimize additional tests: cost savings/dose
  - Reduced acquisition phases
- Superior vascular imaging
  - Vessels and concurrent tissue perfusion maps
- Material separation
- Iodine dose reduction
- Metal artifact reduction

Pubmed – Dual energy CT

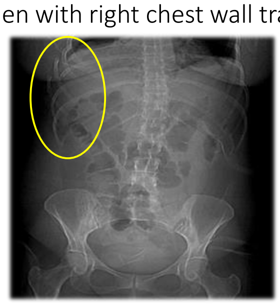
1980 publications



- Angiography: 316
- Head: 100
- Chest: 117
- Cardiac: 193
- Abdomen: 77
- Liver: 160
- Gout: 59

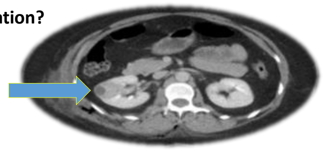
45Y Women with right chest wall trauma

Multiple right ribs fractures



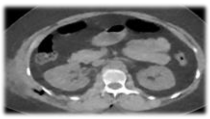
Renal Laceration?

140 kV GSI

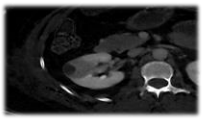


RCC

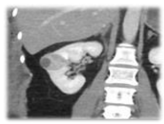
VNC



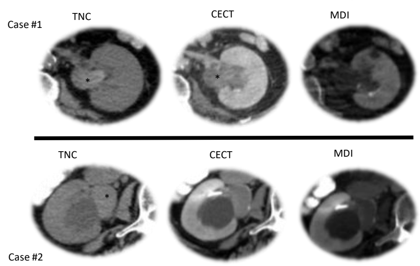
MD-Iodine



Coronal

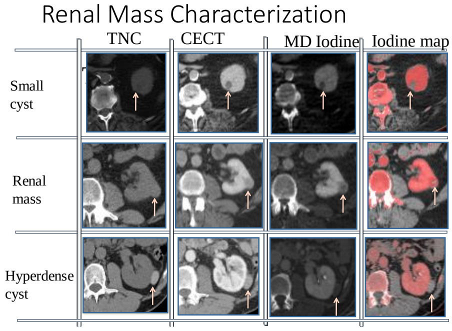


Renal Lesion vs Hemorrhage

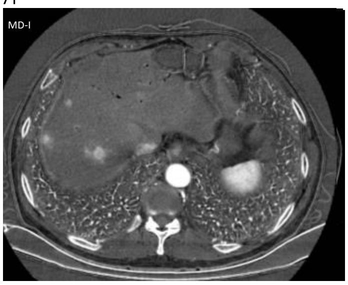


Silva A. Radiographics. 2011 Jul-Aug;31(4):1031-46

Renal Mass Characterization



Hypervascular Liver Lesions



Liver DECT and Hypervascular Lesions Detection

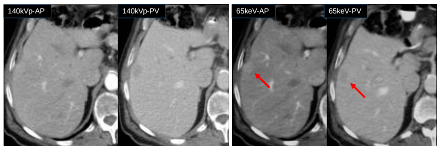
Hypervascular lesion with DECT in arterial phase					
Marin et al.	2009	31	HCC and metastasis from renal cell carcinoma, neuroendocrine tumor & breast	ssDECT (fast kV switching)	80 kVp improved conspicuity of malignant hypervascular hepatic lesions as compared to 140 kVp
Altenbernd et al.	2011	40	HCC	dsDECT (1st generation)	80 kVp images more sensitive in lesion detection than blended and 140 kVp
Shuman et al.	2014	72	HCC	ssDECT (fast kV switching)	50 keV images improved subjective lesion conspicuity with equal detection at 77 keV
Altenbernd et al.	2016	20	Uveal melanoma	dsDECT (1st generation)	80 kVp images more sensitive in lesion detection than blended and digital subtraction angiography

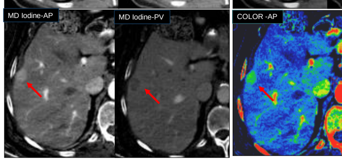
DECT and CE-Liver MRI

- 52 patients
  - 236 hypervascular lesion (31 Benign and 205 Malignant)
  - 3 Readers (3 Read sessions-SECT, 65 keV and MD-I)
  - Lesion detection superior on MD-I for all readers (80% vs 65%)
  - Higher lesion to liver CNR

Muenzel D et al. European Jour of Radiol 2017
Pfifer D et al. Abdomeninal Imaging 2018

Liver Nodule Characterization in 55 yr-old-man with HBV cirrhosis



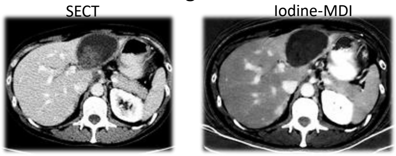


Anzidei M et al. Clin Radiol. 2015 Sep;70(9):966-73.
Altenbernd JC et al. Acta Radiol. 2015 Nov;56(11):1293-9.
Wang Q, Eur J Radiol. 2014 Oct;83(10):1759-64.
Dai X et al. Eur J Radiol. 2013 Feb;82(2):327-34.
Lee JA, et al. Eur J Radiol. 2013 Apr;82(4):569-76.

Treatment monitoring –RFA HCC and RCC

SECT

Iodine-MDI



TNC

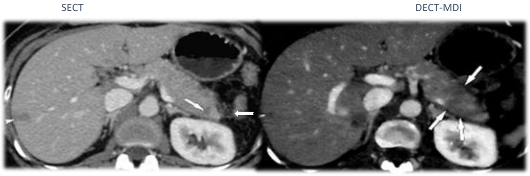
SECT

Iodine map

65 year old with loss of weight

SECT

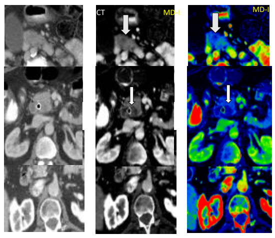
DECT-MDI



DECT Improved Detection of Diffuse Process in Pancreas-AIP

Marin et al Radiology 2009, Yeh et al AJR 2009,Schindera et al Radiology 2008

Poratl Phase Dual Energy CT: Small PDAC



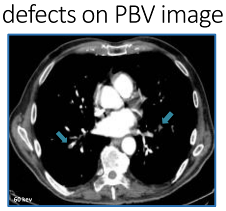
Patino M et al.
RSNA 2016
Prochowski A et al.
SCBTMR 2016

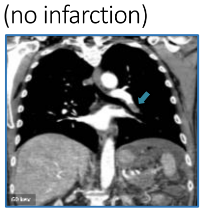
CT Performance for PDAC Diagnosis-Staging

Study	n	Phases	CT	Sensitivity		
				All M	PDAC	Small PDAC
Bluemke et al 1995	64	Mp	ss	-	89%	-
Ichikawa et al 1997	21	Bp	ss	-	76.2%	58%
Irie et al 1997	8	Bp	ss	-	-	62.5%
Diehl et al 1998	76	Bp	ss	-	97%	-
Legman et al 1998	27	Bp	ts	-	92%	-
Sheridan et al 1999	31	Bp	ss	93.5%	-	-
Bronstein 2003	18	Tp	Ss/ms	-	-	77%
Fletcher 2003	30	Tp	Ss/ ms	97%	-	-
Takakura et al 2011	32	Tp	ms	-	94%	-
Prochowski et al 2015	117	Mp (PVP)	ss	95%	98.8%	96.4%

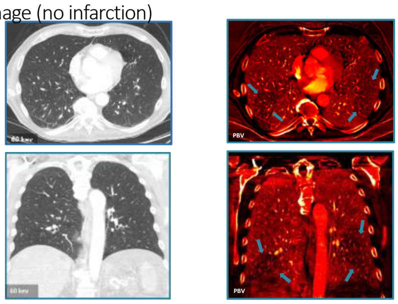
Mp: Monophasic examination; Bp: Biphasic examination; Tp: Triphasic examination; ssCT: single slice CT; tsCT: two slice CT; msCT: multislice (>4) CT. M: malignancies

DECT: Pulmonary embolism with segmental defects on PBV image (no infarction)



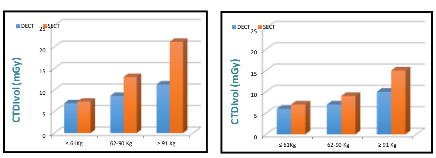


DECT: Pulmonary embolism with segmental defects on PBV image (no infarction)



Radiation Dose

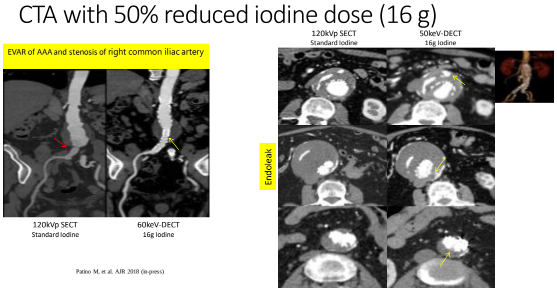
Our institutional data and prior studies demonstrate that chest DECT can have similar or lower radiation doses as compared to the single energy CT.



Pulmonary embolism protocol | Routine chest protocol

Comparison of radiation doses between DECT and SECT for both routine chest and pulmonary embolism (PE) protocols in different weight groups (≤61 Kg, 62-90 Kg, ≥ 91 Kg).

CTA with 50% reduced iodine dose (16 g)



Patino M, et al. AJR 2018 (in-press)

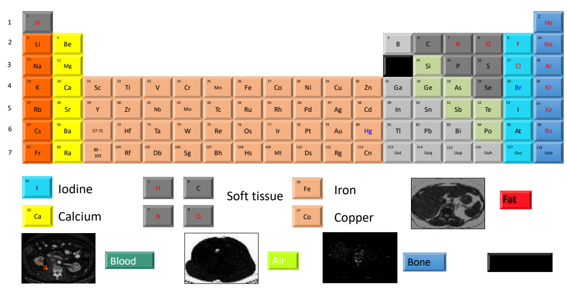
Ultra-Low Iodine CTA-High Risk Patient (CIN)

The Spectral acquisition was consecutively performed after routine contrast enhanced CT angiogram using 30 mL of 370 mg/ml iodine contrast

140 kVp | 60 keV | 50 keV

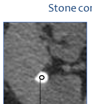
Agrawal M et al. Radiograhics 2014
Fuentes JM et al. Radiographics 2015

Materials evaluated on GSI



Stone Composition & Treatment Decisions

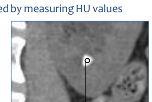
Stone composition evaluated by measuring HU values



<400 HU

Uric Acid Stone 5-10%

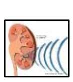
Medical Management
Allopurinol
Treatment of Hyperuricemia



> 500 HU

(Struvite 5-15%)

(Brushite, Cystine, COM)



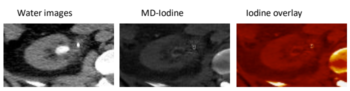
ESWL

PCNL

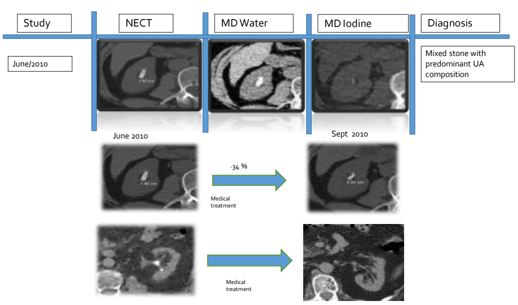
Motley G. Urology 2001;58(2):170–173.
Kim SC. Urol Res 2007;35(6):319–324.
Mostafavi MR. J Urol 1998;159(3):673–675
Coll DM. AJR 2002;178(1):101–103.
Perks AE. Urology 2008;72(4):765–769.

Kidney Stone Composition: Meta-analysis

- UA vs. Non UA stone differentiation in 734 stones
  - 100% Sensitivity & 99.7% Accuracy

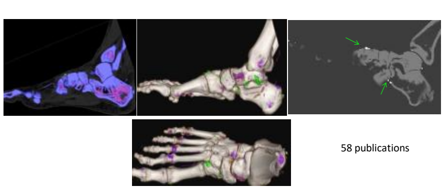


Stolzman P. Urol Res 2008, Graser A. Invest Radiol 2008, Matlaga B. Urology 2008, Graser A . Eur Radiol 2009, Thomas C. Eur Radiol 2009, Boll D. Radiology 2009,, Hidas G. Radiology 2010, Manglaviti G. AJR 2011, Kulkarni N. JCAT 2013.



Gout diagnosis

DECT can help in the diagnosis of gout (articular deposition of Calcium Urate crystals).

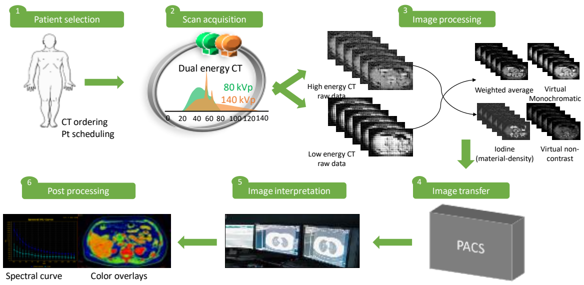


58 publications

International consensus Gout guidelines

Choi HK et al Ann Rheum Dis. 2012 Sep;71(9):1466-71.

CT Image Chain : Which step of Workflow does DECT affect?



Team…

Radiology Specialty leaders	Technologist Champion
IT	Vendor

Clinical Adoption of DECT

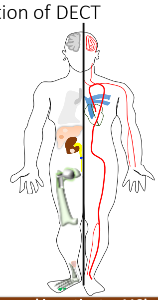
Lesion Detection and Conspicuity
- Inflammatory lesions
- Malignancy
- Tumor staging
- Post-intervention (e.g. renal ablation, post-op)
- Bowel wall enhancement

Lesion Characterization
- Hemorrhage Vs Calcium
- Hyperdense lesion Vs Solid lesion

Therapeutic Response Assessment
- Iodine Concentration

Material Separation
- Renal stones composition analysis
- Liver fibrosis
- Fatty liver
- Gout
- Bone marrow edema
- Tendons
- Ventilation

Artifact Reduction
- Posterior fossa imaging
- Metal artifact reduction



Material Separation
- Contrast staining vs hemorrhage
- Calcification vs hemorrhage
- Plaque characterization

Definition
- Vascular anatomy
- Perfusion evaluation
- Contrast extravasation

Surgical Planning
- Donor evaluation – liver and renal

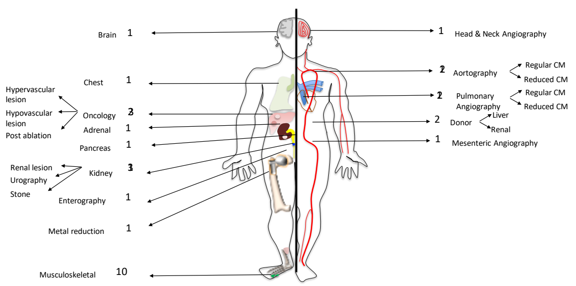
Virtual non-contrast images

Contrast Media Reduction

DECT protocols must be ideally used in patients <118kg (260lb) or transverse diameter <45cm for optimal image quality

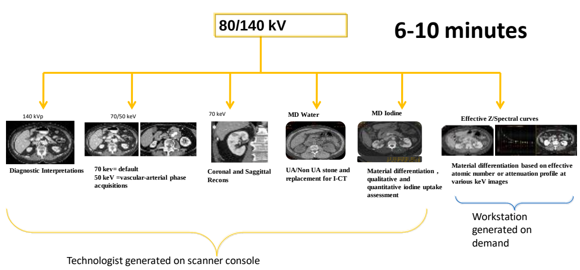
Go slow..(start with key protocols)....

...then grow

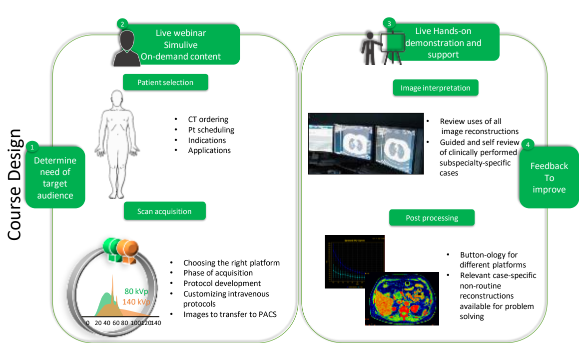


Current DECT protocols in different body regions at our institution

DECT Image Processing



Megibow A and Sahani DV. AJR 2012



Future Perspectives with DECT

Workflow

- Automatization
  - Scheduling
  - Image transfer
  - Post-processing
- Customized protocols

Quantitation

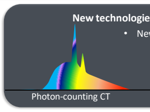
- Variance of HU across VMC images from all scanners
- Material quantitation accuracy across platforms (biomarker)
- Quantification of additional materials (e.g. Fat, Fe, Zn)

Safety

- Further optimization of radiation dose
  - Screening
  - Pediatric patients
- Ultra low CM protocols
- Bariatric DECT

New technologies

- New contrast media



Photon-counting CT

Summary

- DECT has several potential applications in clinical care
  - For improved detection, characterization, staging and response assessment.
  - Material separation
  - Low iodine dose CTA
  - Artifact reduction
- The combination of low-kVp/keV series and iodine maps may allow better detection and characterization of primary and secondary lesions.
- Newer generation DECT technology overcomes few limitations
  - Better image quality
  - Lower dose
  - Permits heavier patient scanning
  - Desirable workflow

Summary: Practice Pearls

- Establishing a technologist-based workflow model is key
- Gradual adoption of DECT into existing CT practice
- Efforts to optimize workflow and protocols to meet sub-specialty practice demands
- Invest in education and software upgrades to enhance efficiency

Thank you…

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