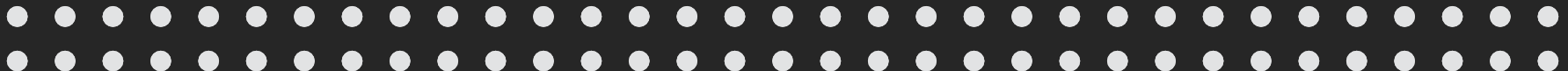


# Dual Energy Computed Tomography (DECT) For the Pediatric Radiologist: Tools to Incorporate Into Clinical Practice

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# Disclosures

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- S. Simoneaux – No disclosures

# Learning Objectives

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1. Dual Energy CT (DECT) basics
2. Renal stone composition analysis
3. Bone subtraction imaging
4. Iodine material specific images
5. Virtual monochromatic imaging

# Dual Energy CT (DECT) – The Basics

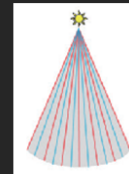
- What is Dual Energy CT (DECT)?
  - Two sets of images acquired at both high- and low-energy spectra
  - Also called “multi-energy” or “spectral” CT
- Different approaches to DECT image acquisition

## Dual Source



- Two independent x-ray tubes
  - Low = 70-80 kVp
  - High = sn140 – 150 kVp
- Two detector arrays

## Rapid kV switching



- Single x-ray tube
  - Rapidly alternates from low (80 kVp) to high (140 kVp) energies during gantry rotation
- Single detector

## Dual-layer Detector



- Single x-ray tube
  - High = 120 kVp
- Single multi-layered detector
  - Separate low and high energy photons

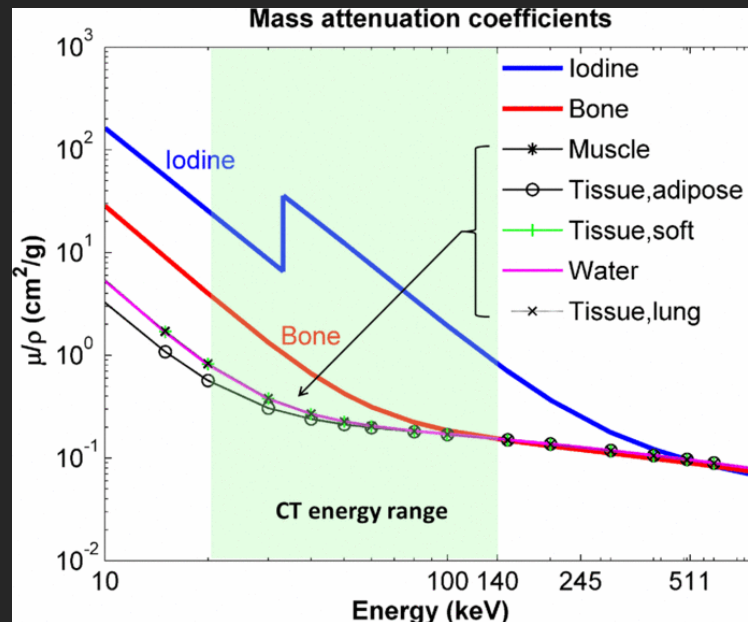
## Split Filter System



- Single x-ray tube
  - Gold (au) and Tin (sn)
  - Splits beam into two energies before reaching patient
- Single detector

# Dual Energy CT (DECT) – The Basics

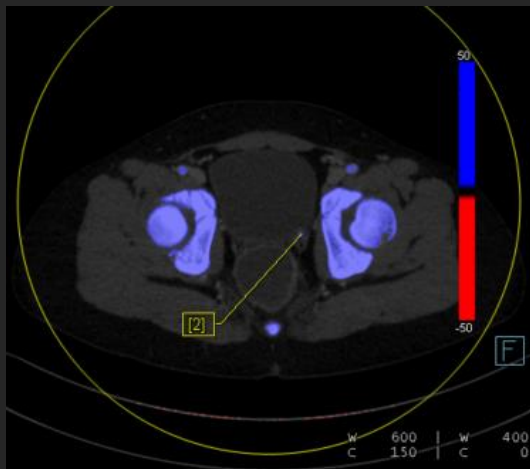
- WHY image at two different energies?
- Different materials (e.g. *calcium* , *fat*, *iodine contrast*) have unique k-edge characteristics → result in differential HU on CT
  - Linear attenuation coefficient values are different at low and high keV
  - By evaluating HU at *low* and *high energy* we can more effectively separate different materials in the body



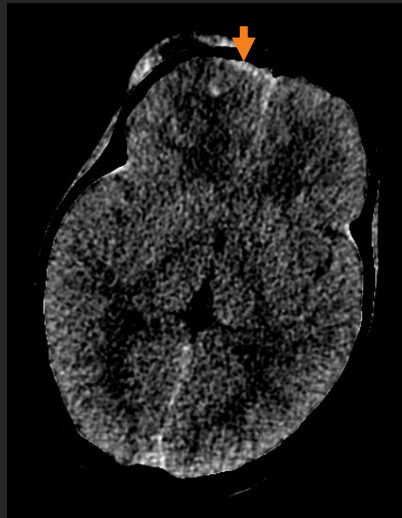
*Attenuation values of MATERIALS in the body change at different energies*

# Dual Energy CT – The Basics

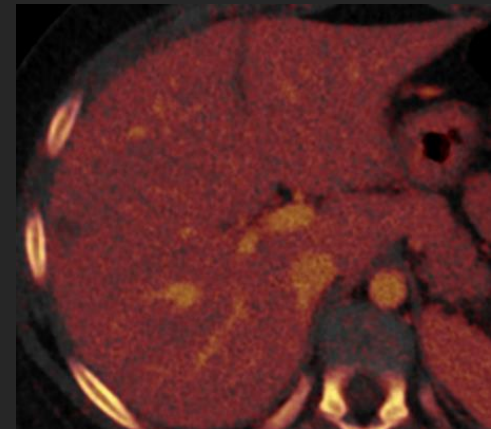
- Material composition analysis
  - Materials are differentiated based on attenuation characteristics
  - Several ways to utilize:
    - “Characterize an unknown structure” (eg. Renal stone composition)
    - “Isolate and remove material” (e.g. Bone subtraction, virtual non-contrast)
    - “Isolate and overlay material” (e.g. Iodine selective overlay)



Renal Stone Composition



Bone Subtraction



Iodine Selective Overlay

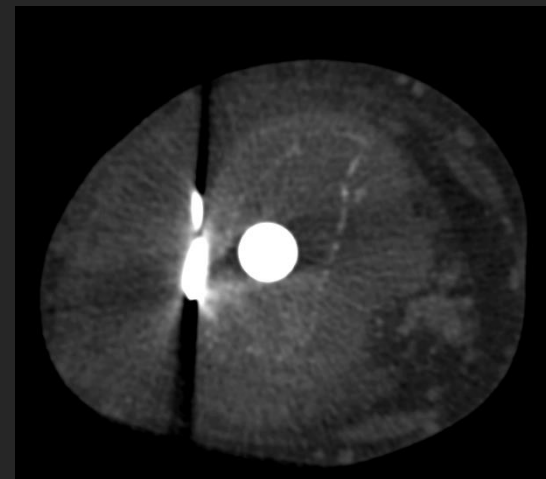
# Dual Energy CT – The Basics

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- *Mono-energetic imaging*
  - Extrapolate very low (40 keV) and very high (>150 keV) energy images
    - Low energy → accentuate iodine-based contrast
    - High-energy → reduce beam hardening artifact from metal hardware



Virtual mono 40 keV



Virtual mono 150KeV

# Dual Energy CT (DECT) – Radiation Exposure

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- In adults
  - Evidence that radiation exposure of DECT is equivalent to conventional single energy 120 keV images
- In pediatrics
  - Evidence that optimized scanner technology allows DECT to deliver equivalent or smaller radiation exposure than conventional single energy CT
    - 2016 – Zhu et al. *Dual-energy compared to single energy CT in pediatric imaging: A phantom study for DECT clinical guidance*. *Pediatr Radiol* (2016) 46: 1671-1679
    - 2019 – Weinman et al. *Dual energy head CT to maintain image quality while reducing dose in pediatric patients*. *Clinical Imaging* (2019) 55: 83-88.



# DECT – Incorporate Into Clinical Practice

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- How to use DECT?
- Many clinical applications of DECT can be incorporated into daily clinical practice of Pediatric Radiology
  1. Renal stone evaluation
  2. Trauma imaging → Head CT
  3. Trauma imaging → Abdomen/Pelvic CT
  4. Vascular imaging → Neuro, Body, Chest
  5. Orthopedic imaging → Orthopedic hardware evaluation

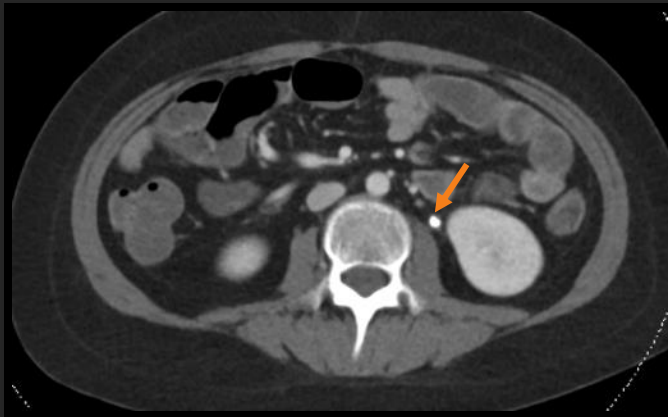
# DECT – Renal Stone Imaging

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- *~70% of pediatric patients have urinary metabolic abnormality*
  - Jackson EC and Avendt-Reeber M. *Urolithiasis in Children – Treatment and Prevention*. Curr Treat Options Peds (2016) 2: 10-22.
- All children diagnosed with renal stone are evaluated for underlying stone composition
  - Serum electrolytes with serum calcium and phosphorus
  - 24 hour urine collection
- Stone composition affects both treatment and prevention strategies
- Common stones seen in pediatrics:
  - Uric Acid (5%)
  - Non-Uric Acid
    - Hydroxyapatite (~80%)
    - Calcium oxalate
    - Cystine
    - Struvite

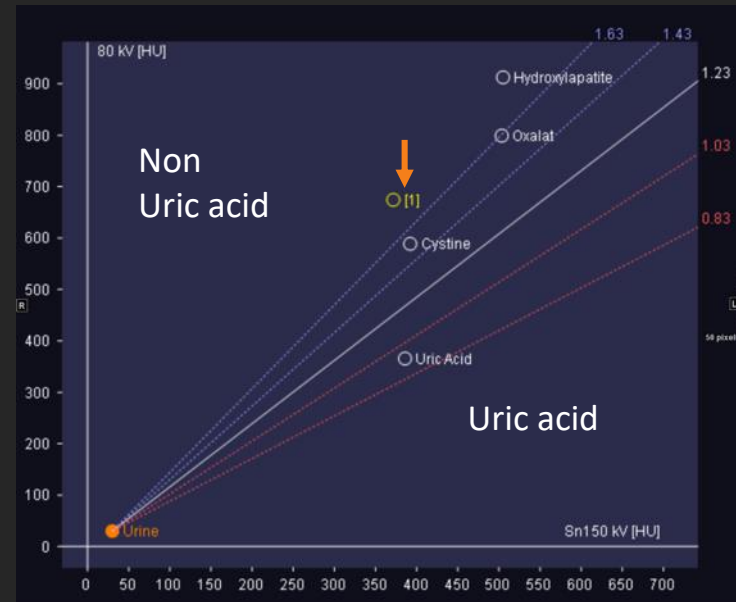
# DECT – Renal Stone Imaging

- If CT performed, DECT can add stone composition analysis
  - X-ray attenuation profile of the predominant materials within stones (hydroxyapatite, oxalate, cystine, uric acid) are significantly different at high and low kV
  - ROI drawn on renal stone is plotted on chart to determine stone composition

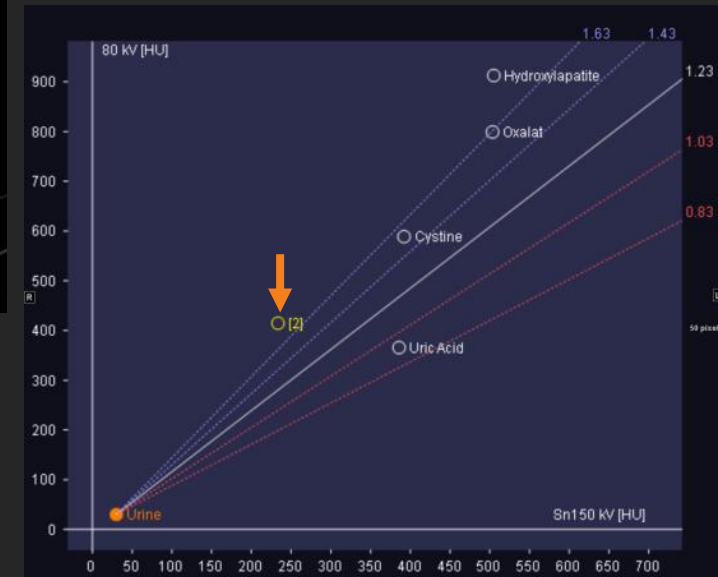
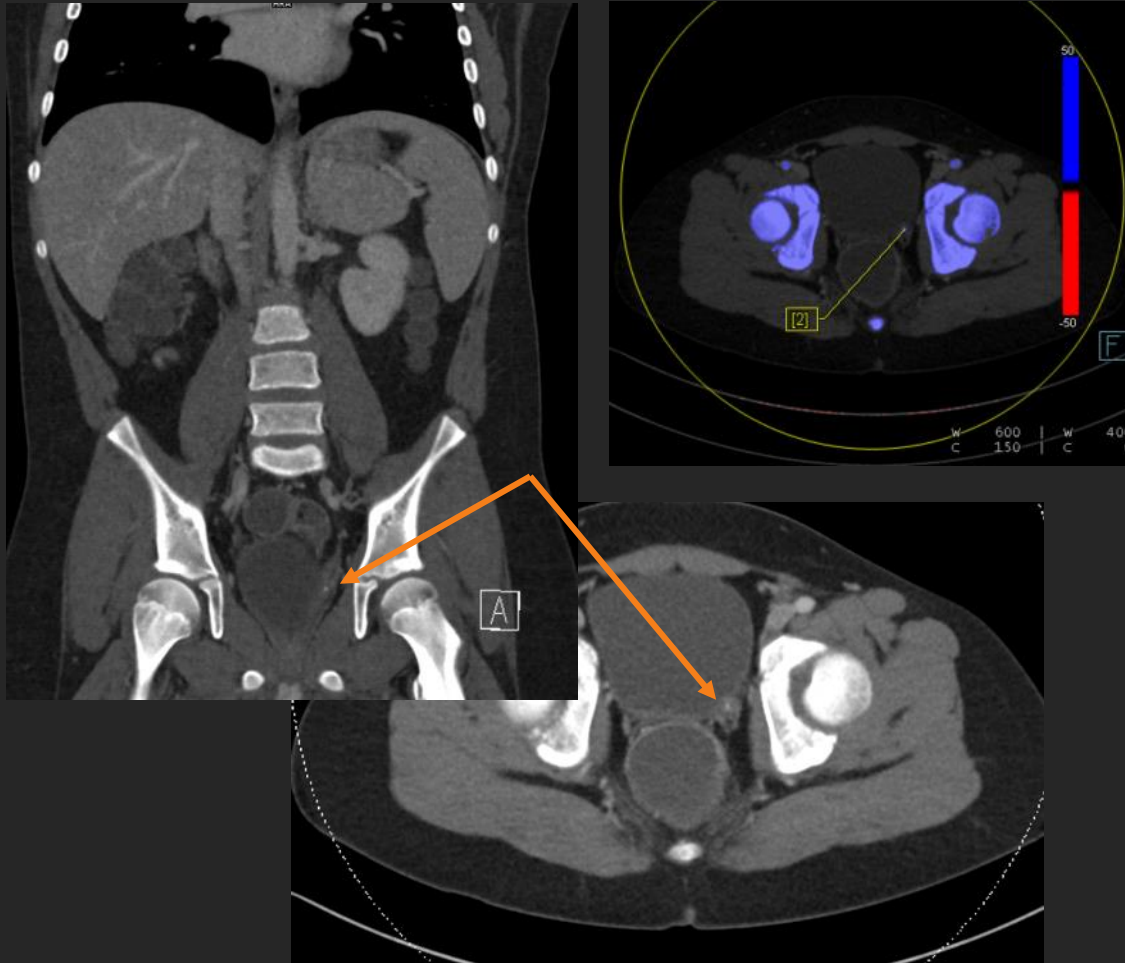


18 yo male, flank pain and hematuria

- Left hydronephrosis on ultrasound
- Hyperdense stone in the proximal LEFT ureter



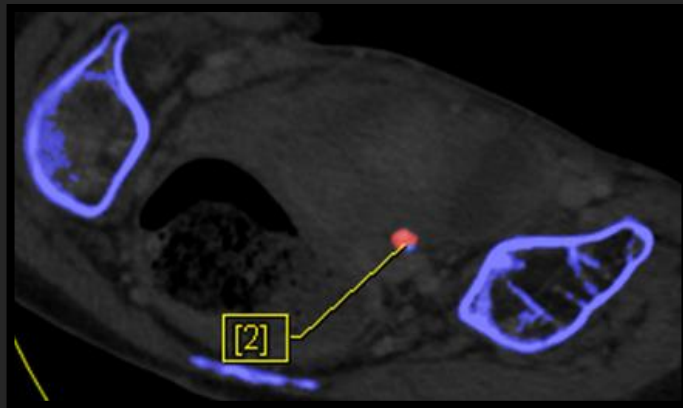
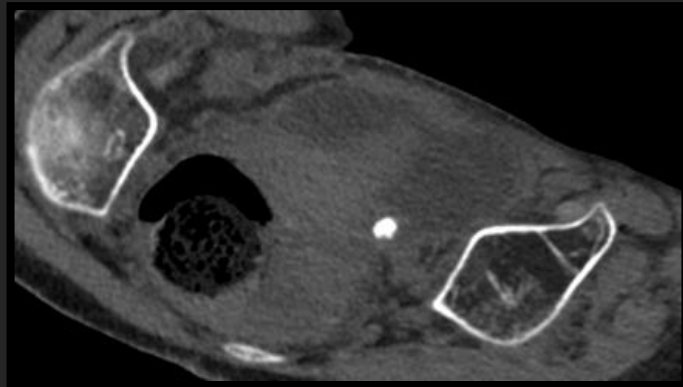
# DECT – Renal Stone Imaging



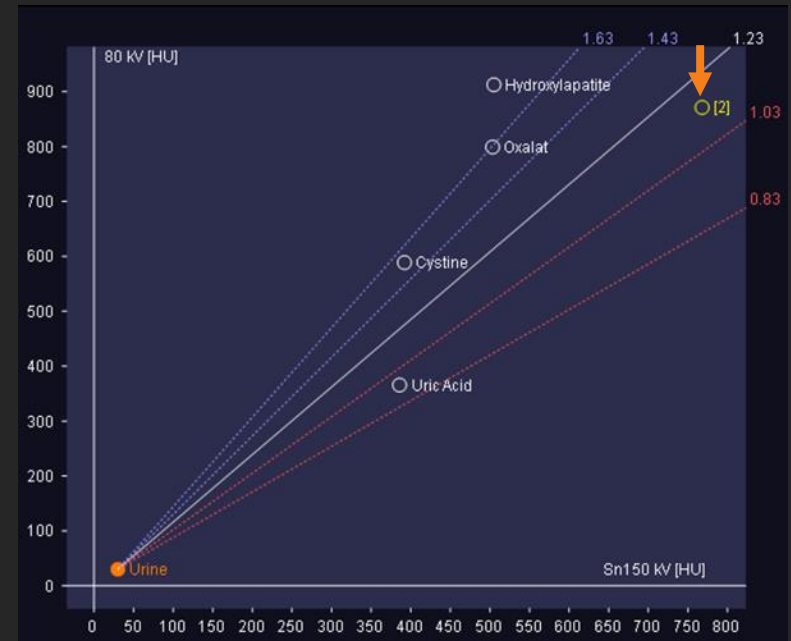
Stone composition analysis with DECT demonstrates non-uric acid stone

11 yo male; hematuria

# DECT – Renal Stone Imaging



16 yo male with abdominal pain



Stone analysis shows mixed composition, likely partially urate stone

# DECT – Trauma Imaging(Neuro CT)

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- Non-contrast head CT is the recommended imaging study for evaluation of head trauma in children
  - Acute hemorrhage higher density than normal brain parenchyma
  - However, small acute extra-axial hemorrhage adjacent to bone may be easily missed due to its size and similar density to bone
- DECT material composition analysis can be used to virtually “subtract” bony calvarium, increasing conspicuity of acute hemorrhage
  - Recent study in *Emergency Radiology* demonstrated Bone Subtraction CT images were significantly superior to simulated standard CT images in detecting small epidural/subdural hemorrhage
    - Naruto N et al. *Dual-energy bone removal computed tomography (BRCT): preliminary report of efficacy of acute intracranial hemorrhage detection. Emerg Radiol* 2018(25): 29-33.

# DECT – Trauma Imaging(Neuro CT)

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- 9 yo male, MVC with altered mental status

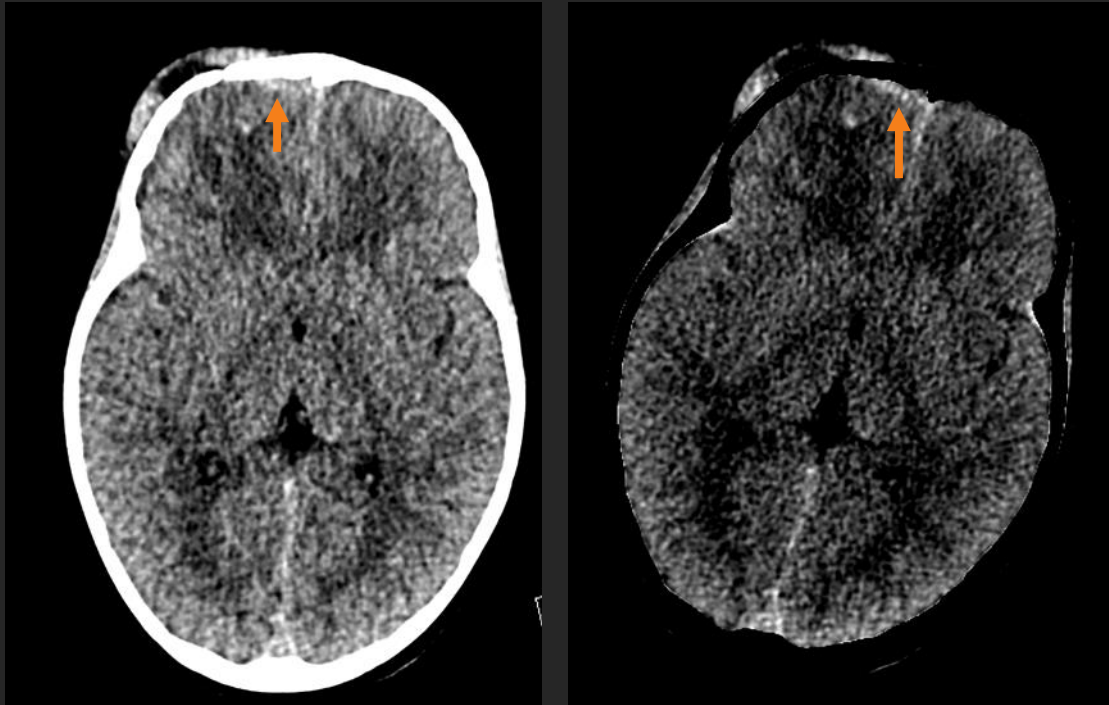


Bone subtraction increases conspicuity of small left frontal subdural hematoma.

# DECT – Trauma Imaging(Neuro CT)

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5 yo Female; fall with scalp hematoma



Trace subdural hemorrhage along the right frontal calvarium (→) could be mistaken for cupping artifact, but persists and is more conspicuous on bone-subtracted images.



# DECT – Trauma imaging (Abdomen/Pelvic CT)

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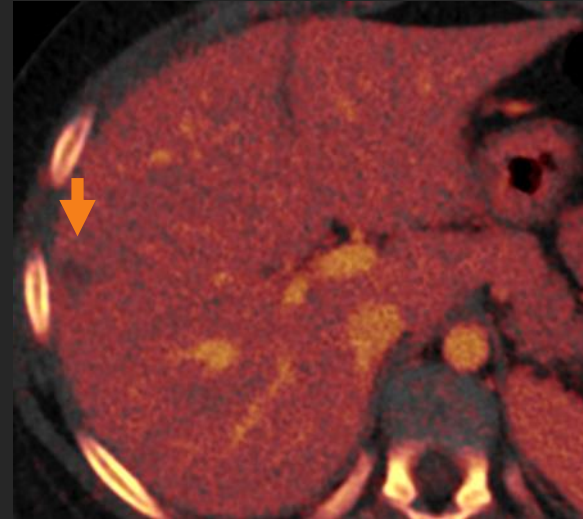
- CT plays an important part of the workup of pediatric patients with blunt abdominal and pelvic trauma
  - Identification of solid-organ and hollow-visceral injury
    - Spleen
    - Liver
    - Kidneys
    - Bowel
- DECT material composition analysis can be used to generate iodine-selective imaging can increase conspicuity of traumatic injuries making them easier to detect and categorize and assist in evaluation of active contrast extravasation

# DECT – Trauma imaging (Abdomen/Pelvic CT)

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- Iodine Selective Imaging provides qualitative assessment of contrast media distribution in solid organs, increasing conspicuity of solid organ injury

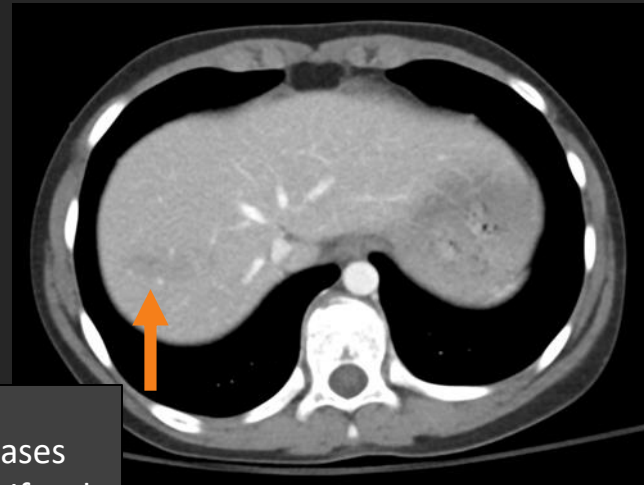
6 yo female; MVC with abdominal pain and “seatbelt sign”



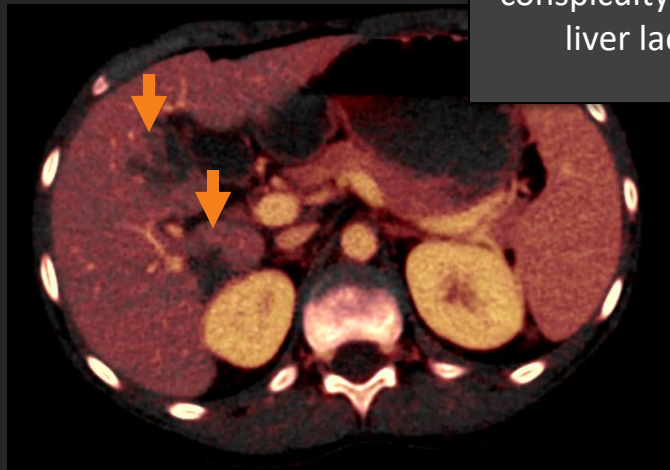
Iodine map increases conspicuity  
of AAST grade 1 injury right  
hepatic lobe

# DECT – Trauma imaging (Abdomen/Pelvic CT)

8 yo male; MVC trauma with elevated LFTs

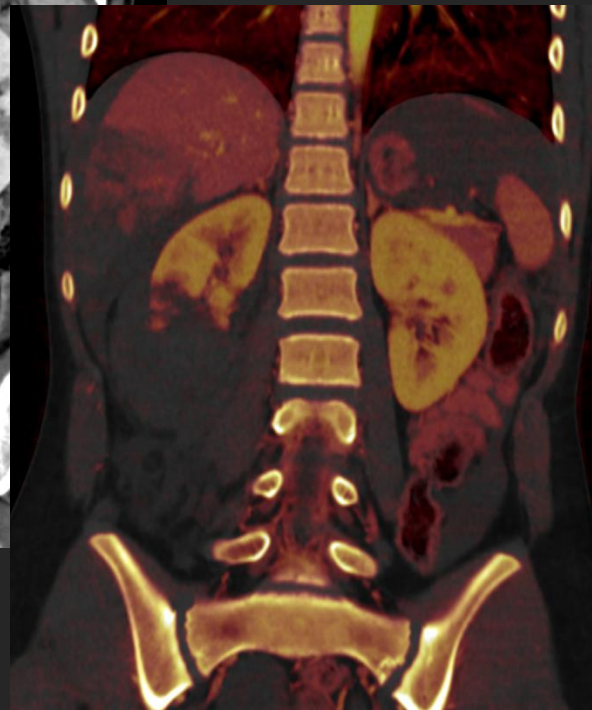
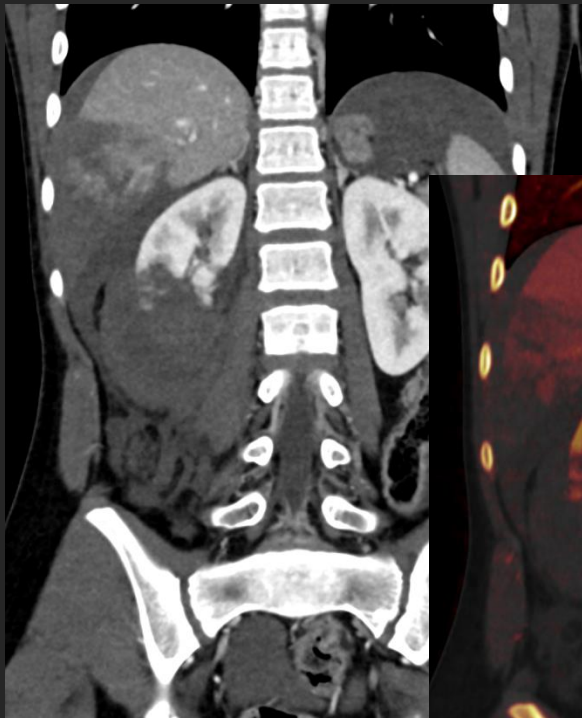


Iodine map increases  
conspicuity of multifocal  
liver lacerations

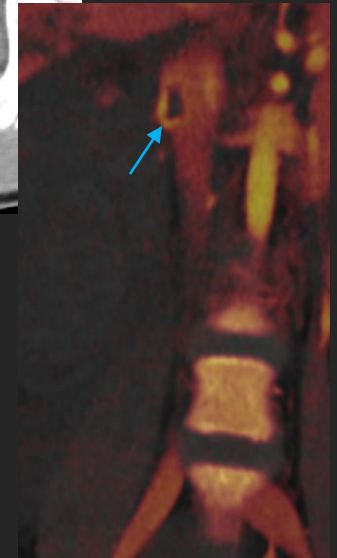


# DECT – Trauma imaging (Abdomen/Pelvic CT)

11 yo Female, kicked by horse



Iodine map also confirms right renal vein thrombus (→).

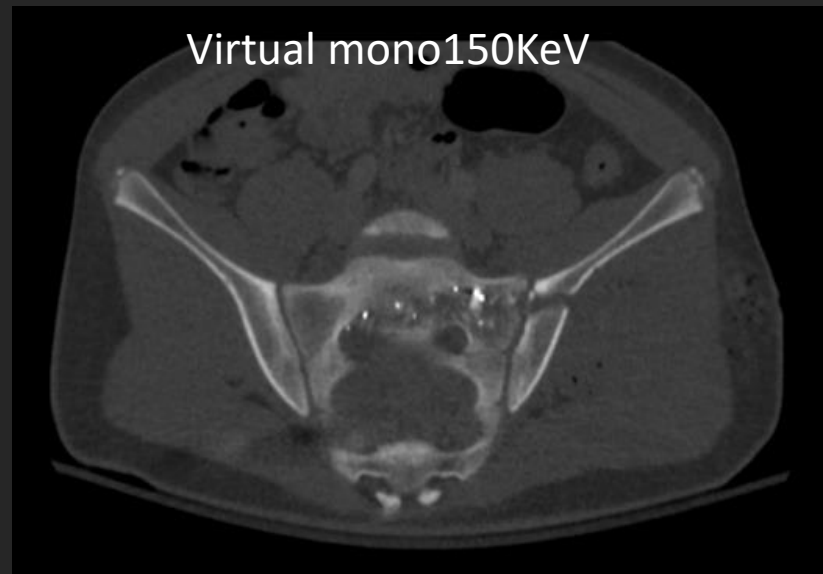


Grayscale DECT images demonstrate high grade injury of the inferior pole right kidney with large perinephric hematoma. Iodine map confirms lack of perfusion to the affected renal parenchyma (AAST grade 4 injury) and excludes contrast extravasation. Also seen is AAST grade 3 liver injury.

# DECT – Trauma imaging (Abdomen/Pelvic CT)

- DECT material composition analysis and virtual monoenergetic images at high keV (110-150) can significantly reduce metal artifacts and improve evaluation of penetrating trauma

15 yo male, GSW to left hip



Virtual monoenergetic images at 150 kV decreases metallic streak artifact from ballistic fragments, improving evaluation of sacral and iliac bone injury

# DECT - Vascular imaging

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- CT Angiography is routinely used in pediatric patients to evaluate the vascular system
- DECT material composition analysis can be used to:
  - Virtually “subtract” axial and appendicular skeleton to improve visualization of vessels
  - Virtual monoenergetic images improve evaluation of iodine contrast within vessels
  - Iodine maps can improve visualization of vessels in situ
  - Iodine maps can also be used to evaluate solid organ perfusion



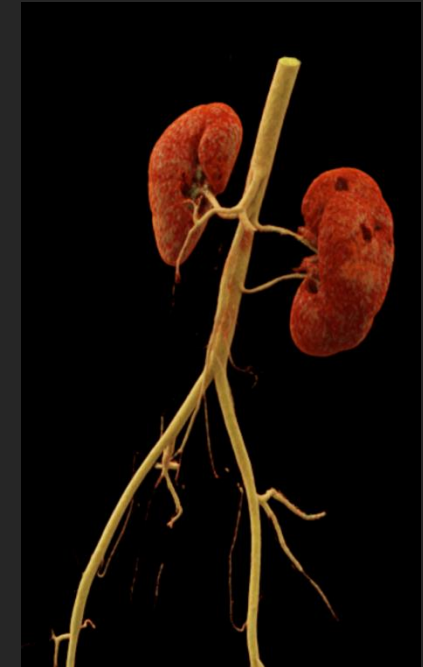
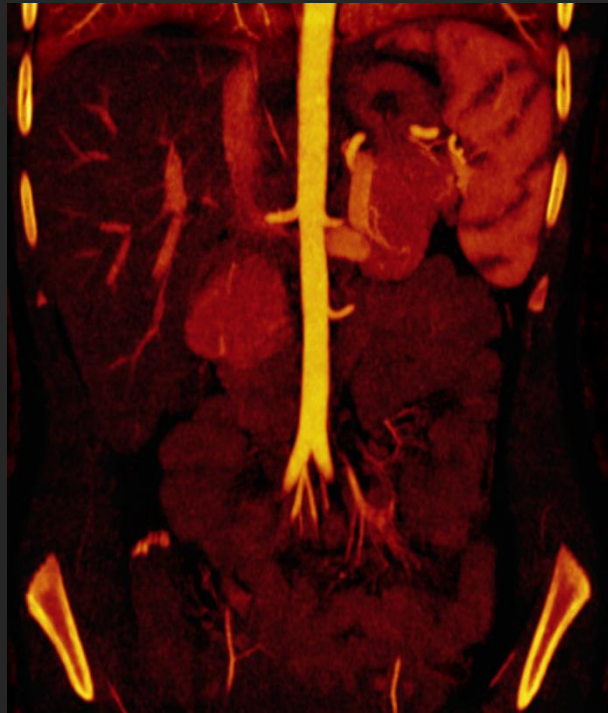
# DECT - Vascular imaging

12 yo female, hypertension and elevated renin level



Virtual mono40KeV

Virtual monoenergetic images at 40 kV and Iodine Map enhances IV contrast conspicuity on abdominal CTA



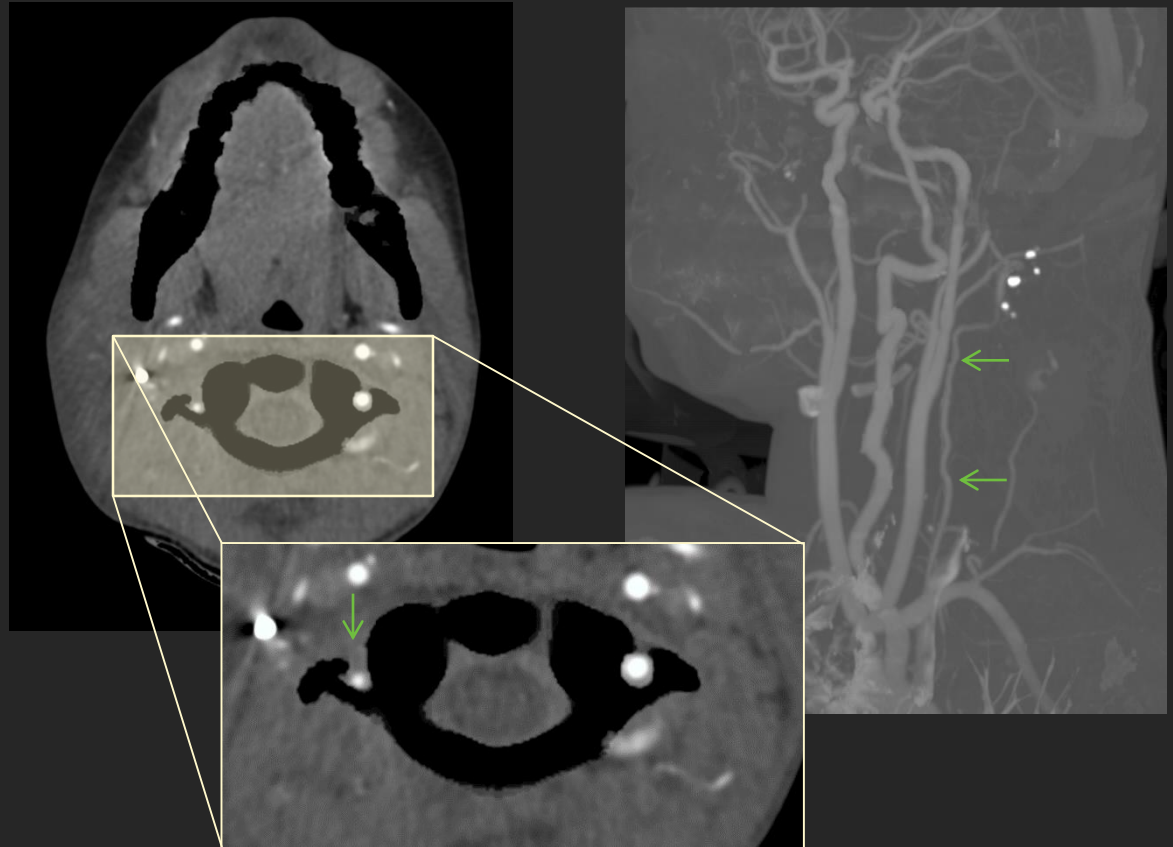
3D rendering with automatic bone removal demonstrates accessory LEFT renal artery, which can be associated with renin-dependent hypertension

# DECT - Vascular imaging

8 yo F, Gunshot wound (GSW) to the neck



Conventional single energy CT from referring hospital with significant metallic streak artifact from retained ballistic fragment limits evaluation of the right vertebral artery (→)



Repeat DECT with bone removal and 3D MIP reformats allows improved visualization of the right vertebral artery (→) and demonstrates Denver grade II vascular injury with >25% luminal narrowing



# DECT – Pulmonary Embolus

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- Dual-energy CTA is widely used in the evaluation of PE in adult radiology practice
  - Conventional CT angiography provides anatomic information
  - Dual-energy CT allows simultaneous evaluation of lung vessels and assessment of lung perfusion
    - Perfusion defects seen in 95% of occlusive emboli and in 6%–30% of non-occlusive emboli
- Several studies have shown that perfusion blood volume (PBV) maps can improve detectability of small endoluminal clots in segmental and subsegmental arteries compared with single-energy CT angiography

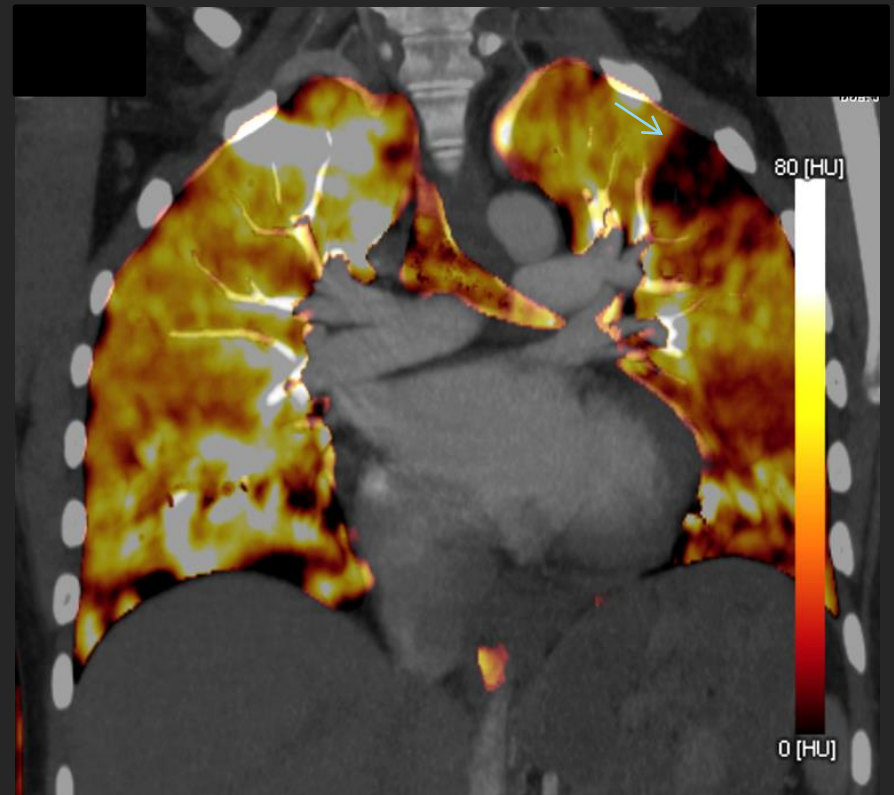
# DECT – Pulmonary Embolus

16 yo female; History of lupus with concern for pulmonary embolism.

- Clot noted on end of dialysis catheter during routine echo.
- Patient reported mid-sternal chest pain and shortness of breath same day.



LUL segmental pulmonary artery thrombus (→) and wedge-shaped region of parenchymal oligemia (→)



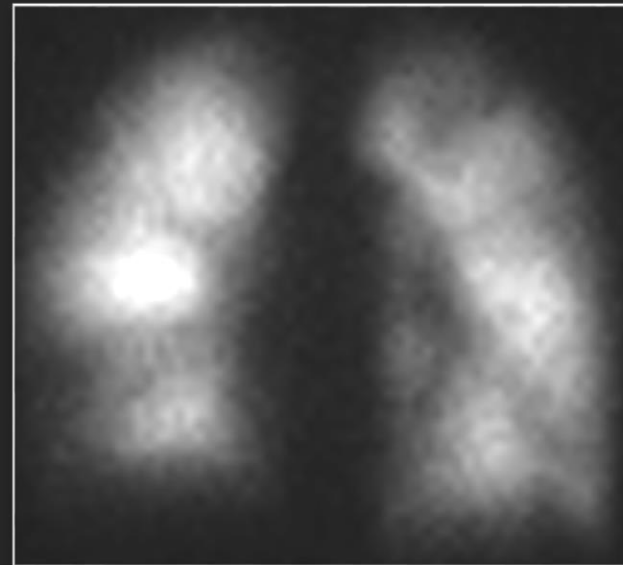
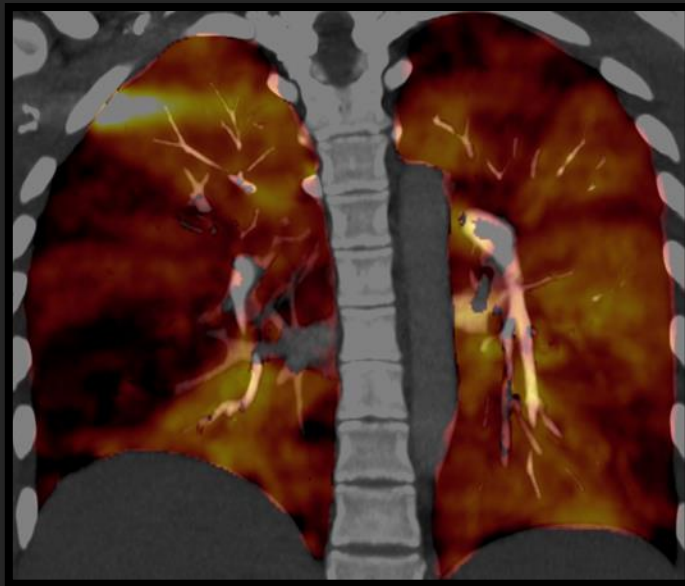
Lung perfusion reformats demonstrate peripheral wedge-shaped defect (→) that corresponds to region of oligemia on grayscale images

# DECT – Pulmonary Embolus

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- In patients with pulmonary emboli, dual-energy CT perfusion defects have shown good correlation with scintigraphic VQ and SPECT findings

17 yo female; known chronic PE



Iodine map and VQ scan performed on the same day show near-identical findings. The pulmonary emboli were no longer visible on CTPA.

# DECT – Orthopedic Imaging

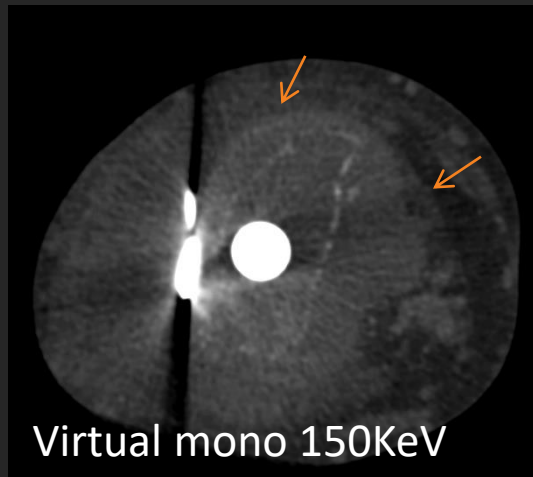
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- Cross-sectional imaging (CT and MRI) are routinely used for evaluation of pediatric musculoskeletal pathology
- **Metallic hardware** can cause significant **artifact** on CT from beam-hardening and photon-starvation effects which degrades image quality, obscures adjacent structures, and decreases diagnostic value of exam
- DECT virtual monoenergetic images at high keV (110-150) can significantly reduce metal artifacts and improve image quality

# DECT – Orthopedic Imaging

- DECT virtual monoenergetic images at high keV (110-150) can significantly reduce metal artifacts and improve image quality

13 yo female S/p limb salvage for proximal tibial osteosarcoma. New leg pain.



Virtual monoenergetic high kV images allow us to visualize new distal tibial mass (→) with large soft tissue component otherwise obscured by metallic streak artifact.



3D rendering with iodine map demonstrates large metastasis in soft tissues of distal lower extremity (→)

# Learning Objectives

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1. Dual Energy CT (DECT) can distinguish clinically relevant materials in the body (calcium, iodine, water, fat) on the basis of k-edge characteristics and differences in attenuation at different kV.
2. With appropriate technical settings DECT is dose neutral in pediatric imaging.
3. Renal stone composition analysis
  - Differentiate hydroxyapatite from oxalate, cysteine, and uric acid stones to guide treatment
4. Bone subtraction imaging
  - Head trauma - Improve conspicuity of intracranial hemorrhage
5. Iodine material specific images
  - Trauma imaging - Increase conspicuity of solid organ injury in blunt trauma
  - Oncologic imaging - improve lesion detection and characterization
  - Bowel imaging - evaluation of bowel wall enhancement in inflammatory bowel disease
  - Vascular imaging - Improved vascular definition in CTA
  - Chest imaging - Demonstrate pulmonary perfusion patterns in pulmonary embolus
6. Virtual monochromatic imaging
  - Reduce beam hardening artifact from metal stents and orthopedic hardware in pediatric patients

# Dual Energy CT (DECT) in Clinical Practice

- Learn more....

REVIEWS AND COMMENTARY • REVIEW

Radiology

## Dual-Energy CT in Children: Imaging Algorithms and Clinical Applications

*Marilyn J. Siegel, MD • Juan Carlos Ramirez-Giraldo, PhD*

From the Mallinckrodt Institute of Radiology, Washington University School of Medicine, 510 S Kingshighway Blvd, St Louis, Mo 63110 (M.J.S.); and Siemens Healthineers, Malvern, Pa (J.C.R.G.). Received October 2, 2018; revision requested October 29; final revision received January 21, 2019; accepted January 24. **Address correspondence** to M.J.S. (e-mail: [siegelm@mir.wustl.edu](mailto:siegelm@mir.wustl.edu)).

Conflicts of interest are listed at the end of this article.

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# Thank You!

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