Multi-energy CT: Clinical Applications

Cynthia H. McCollough, PhD, FAAPM, FACR
Professor of Medical Physics and Biomedical Engineering
Director, CT Clinical Innovation Center
Mayo Clinic, Rochester, MN

DISCLOSURES

Research Support:

NIH	Other
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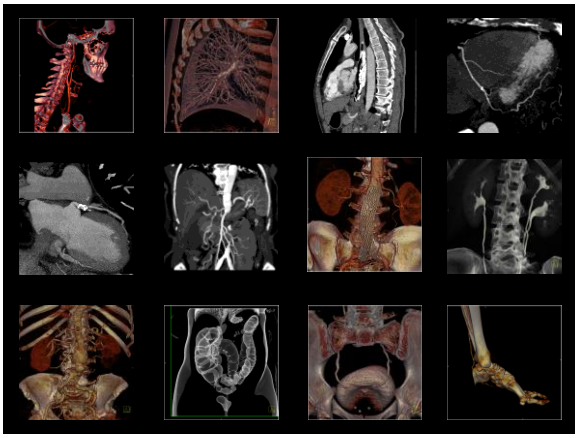
EB 016966	Thrasher Foundation
DK 100227	Siemens Healthcare
HR 046158	
RR 018898	

Off Label Usage
None

What Does CT Do Now Routinely

Anatomic Morphology!

- CT of head, chest, abdomen and pelvis
- Muscoskeletal CT
- CT Angiography
- CT Colonography (large intestine)
- CT Enterography (small intestine)
- Cardiac CT
- CT-guided Intervention



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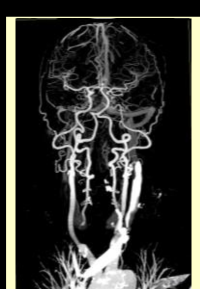
Clinical Motivation

- Different materials can have the same CT number if atomic number differences are offset by appropriate density differences
- CT number depends on x-ray attenuation
  - Physical density (g/cm3) [electron-density]
  - Atomic number (Z)
- Dual-energy CT
  - Allows separate determination of density and Z
  - Can provide material composition information



Courtesy of Prof. Pasovic,
University Hospital of Krakow, Poland

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Dual Energy CT Images

- Low / High energy source images
  - 80 kV and 140 kV images
- Mixed (blended) images
  - Combine low and high energy images together
  - Linear and non-linear blending
- Energy selective image
  - Virtual monochromatic (monoenergetic) images
- Material selective images
  - Iodine image, water image, bone image

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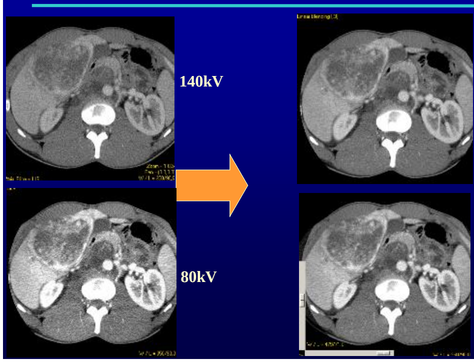
DECT Mixed Images



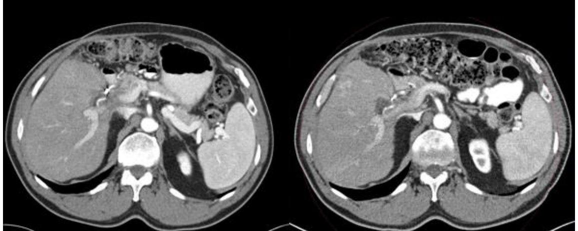
Linear Blend

70% 140kV
30% 80kV

Non-linear Blend

Eusemann et al SPIE 2008

Dual-energy scans need not increase dose



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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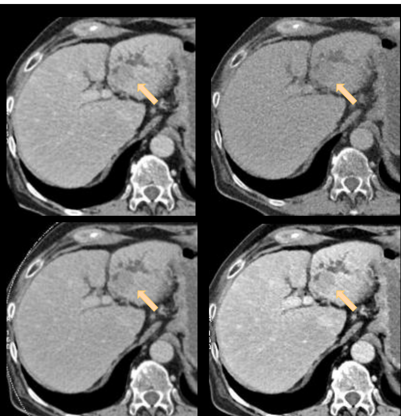
Virtual Monoenergetic Imaging

- Improve iodine contrast
- With energy domain noise reduction*, can be used to improve iodine CNR
  - Increase conspicuity of subtle lesions
  - Allow use of less iodinated contrast media
  - Compensate for poor venous access resulting in slow injection rates
- Reduce metal artifacts

* Leng et al. 2011



80 kV

140 kV

Mixed

50 keV

40 keV

85 keV

120 keV

Silva et al, Dual-Energy (Spectral)CT: Applications in Abdominal Imaging. Radiographics 2011

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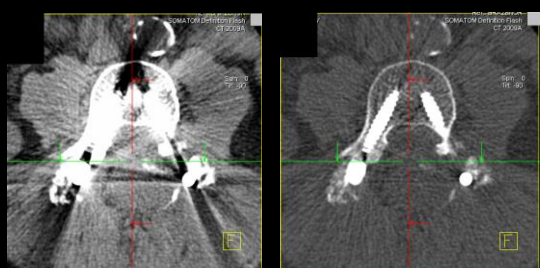
Virtual Monoenergetic – Metal Artifacts

- Use high keV to reduce strength of metal artifacts
- Use low keV to visualize iodine



Standard Image | Monoenergetic Image (105 keV)

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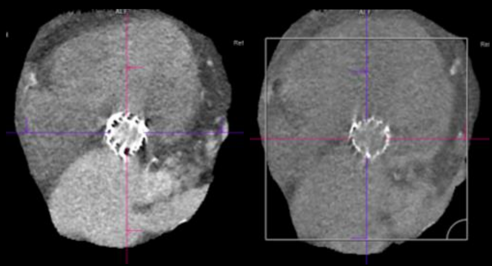
Virtual Monoenergetic – Metal Artifacts

- Use high keV to reduce strength of metal artifacts
- Use low keV to visualize iodine
- Allows fast and flexible reduction of metal artifacts

Transaortic Valve Replacement



70 keV | 130 keV

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Virtual Monoenergetic – Metal Artifacts

- Use high keV to reduce strength of metal artifacts
- Use low keV to visualize iodine
- Allows fast and flexible reduction of metal artifacts
- Is not metal artifact correction
  - No metal detection or sinogram correction
- Especially helpful for complex metal objects

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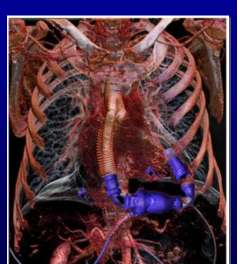
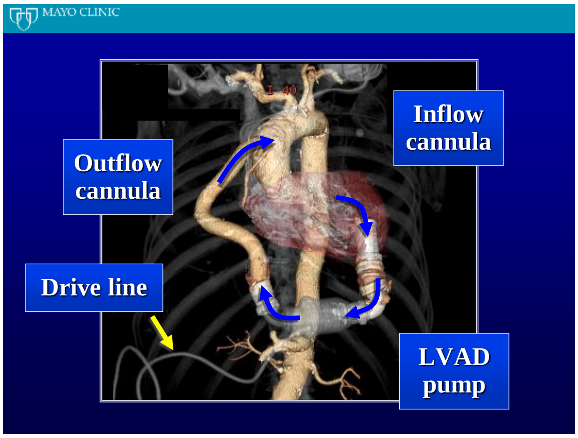
Left Ventricular Assist Device CT (LVAD)

- LVAD's are mechanical pumps that function to reduce the load on the left ventricle
- Bridge to heart transplantation
- Destination therapy for patients ineligible to receive transplants
- Bridge to myocardial recovery



Anders Persson, Linkoping University, Sweden



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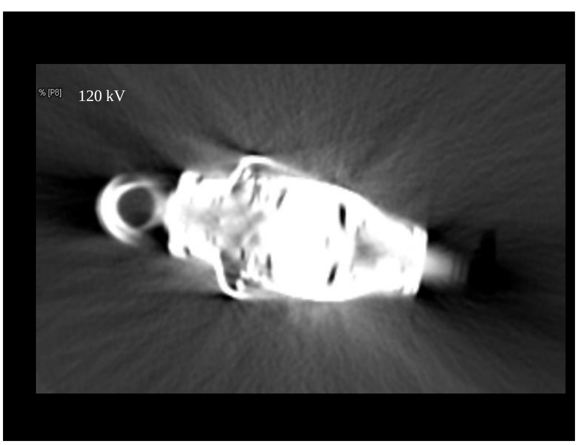
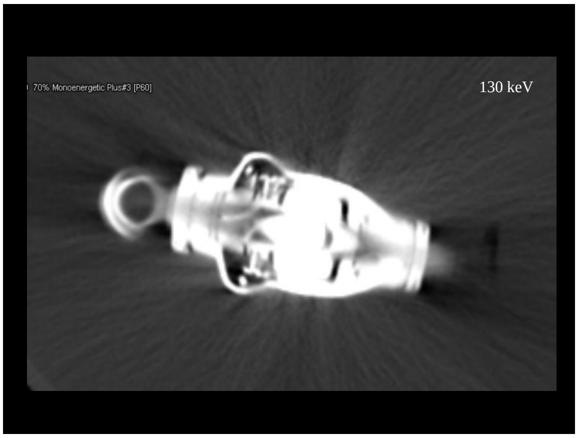
LVAD – Imaging Evaluation

- Echo used to evaluate LV function and cannula thrombus
- Extracardiac components, including the outflow cannula can be difficult to visualize
- CT increasingly used to evaluate LVAD function





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Material Specific Applications

What significant clinical questions
can material composition information help
to answer ?

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Material-specific applications

- Material characterization
  - Kidney stone characterization
  - Gout detection and quantification
  - Silicone breast implant leakage
- Iodine imaging
  - Automated bone removal in CT angiography
  - Plaque removal
  - Blood pool imaging (Perfused blood volume)
- Soft tissue imaging
  - Virtual non-contrast (Iodine removal/highlighting)
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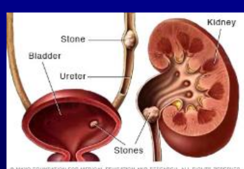
Urinary Stone Characterization

- Kidney stone are common
  - 5.2% US population (ages 20~70)[1]
  - Recurrence rate 50% in 5~10 years[2]
- Stone composition information is important in stone management
  - Directly related to treatment strategy
  - Better understanding of pathogenic factors



From Mayoclinic.org

[1]Stamatelou, 2003
[2]Moe, 2006

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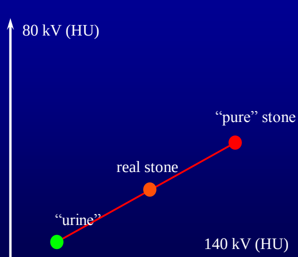
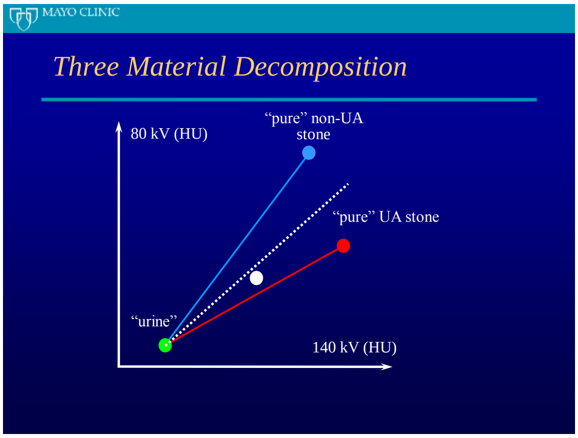
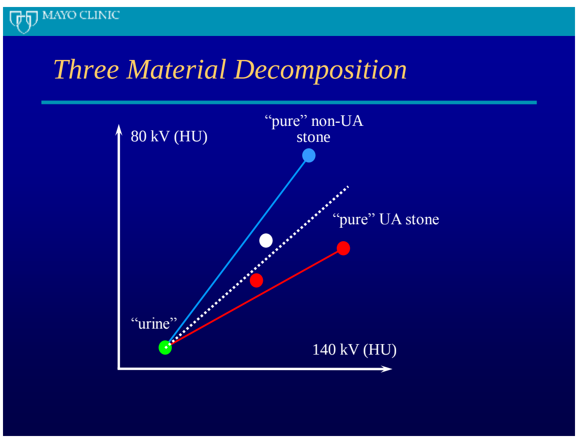
Three Material Decomposition




MAYO CLINIC
Three Material Decomposition
80 kV (HU)
“pure” non-UA stone
“pure” UA stone
“urine”
140 kV (HU)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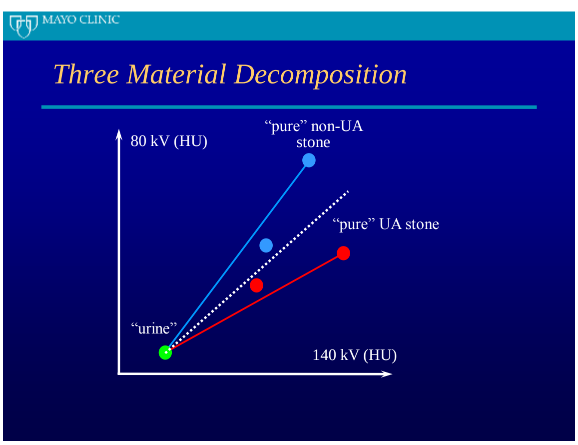
MAYO CLINIC
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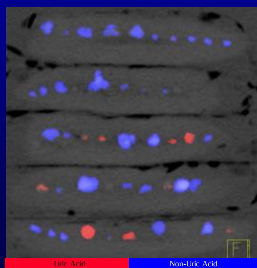
Dual-energy CT Stone Classification

Stones are color coded according to composition



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Dual Source DECT – UA vs Non-UA

- >15 publications on stone composition differentiation using dual energy CT
- Both *in vitro* and *in vivo* studies
- High accuracy, sensitivity and specificity reported
- Used in routine clinical practice

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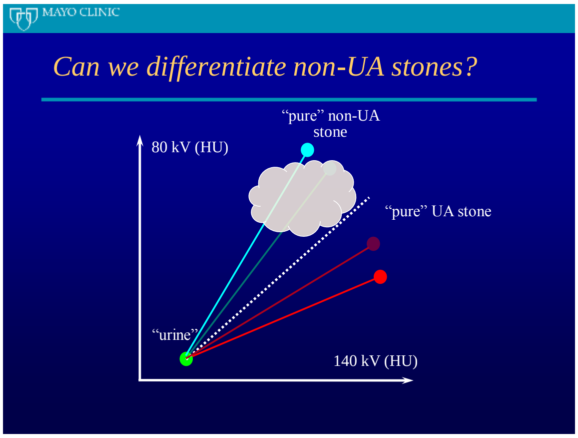
Non-uric acid stones

- Apatite, calcium oxalate monohydrate
  - Most suitable for extracorporeal shockwave lithotripsy.
- Cystine, brushite, calcium oxalate dihydrate
  - Surgical removal (ureteroscopic lithotripsy, percutaneous, nephrolithotomy, and laparoscopic) more appropriate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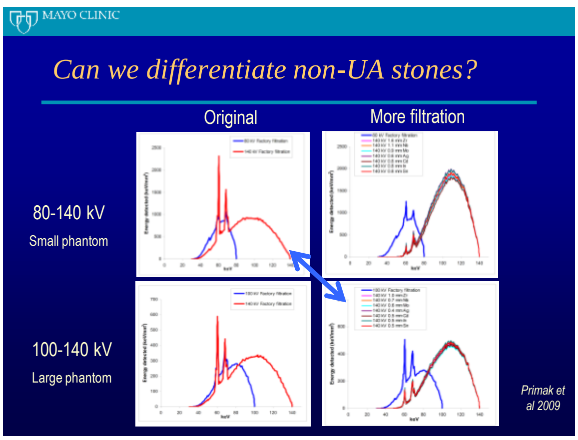
Can we differentiate non-UA stones?
"pure" non-UA stone
80 kV (HU)
"pure" UA stone
"urine"
140 kV (HU)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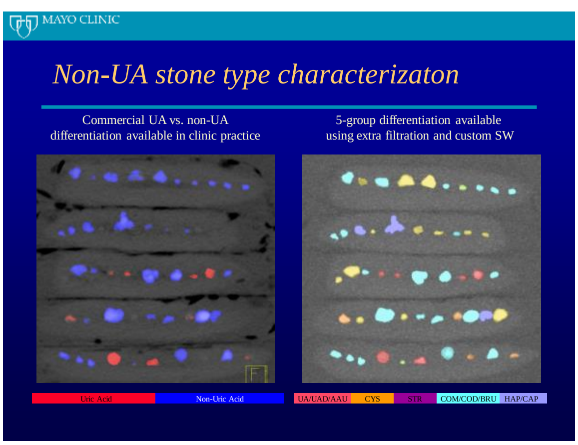
Can we differentiate non-UA stones?
Original
More filtration
80-140 kV
Small phantom
100-140 kV
Large phantom
Primak et al 2009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Non-UA stone type characterizaton
Commercial UA vs. non-UA differentiation available in clinic practice
5-group differentiation available using extra filtration and custom SW
Uric Acid
Non-Uric Acid
UA/UAD/AAU
CYS
STR
COM/COD/BRU
HAP/CAP

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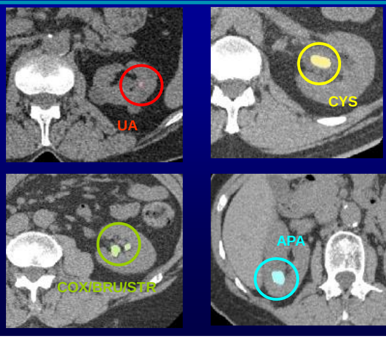
Color-coded stones from in vivo study



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Crystalline Arthropathies

- Prevalence of crystal-induced arthropathies increasing
- Monosodium urate (*uric acid*) crystals → gout
  - painful and disabling chronic disorder, joint destruction
  - decreased renal function, kidney stones, increased CV risk
- Calcium pyrophosphate dihydrate (*calcium*) → pseudogout
  - similarly painful, chronic, disabling
- Basic calcium phosphate (BCP) → calcific periarthritis/tendinitis or destructive arthropathy
  - growing evidence suggest role in pathogenesis of osteoarthritis

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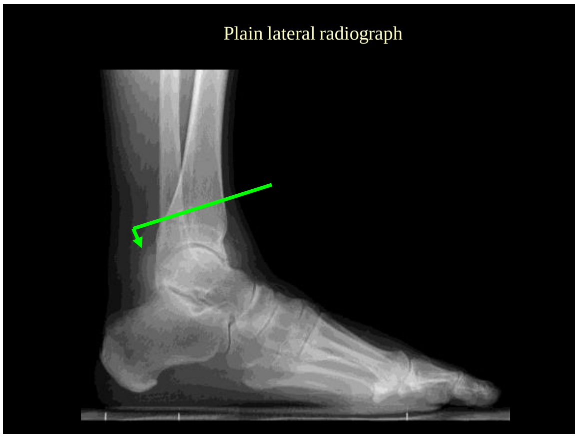
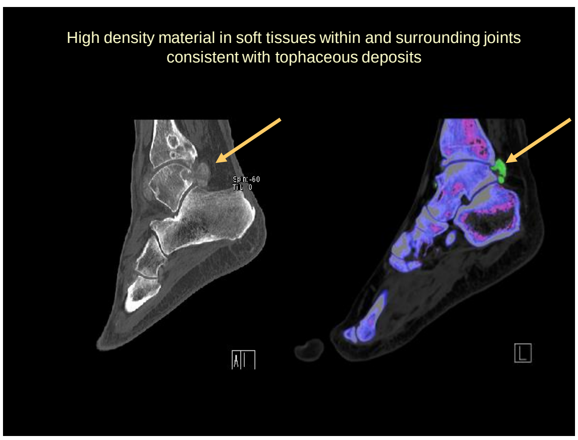
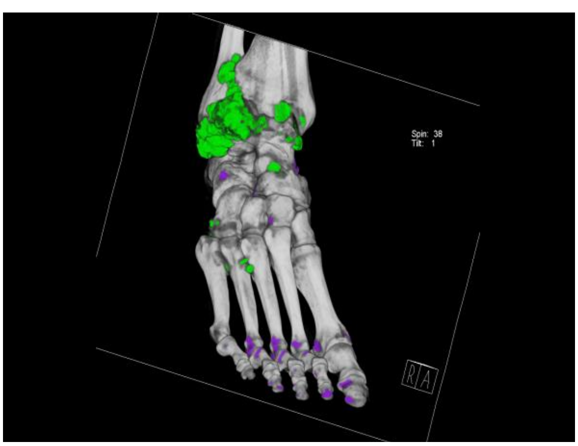
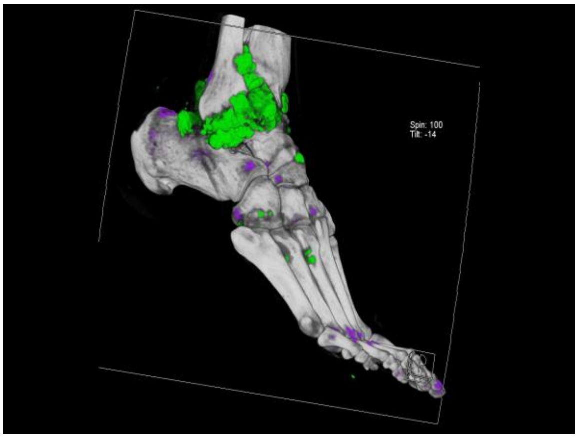
Diagnostic dilemma

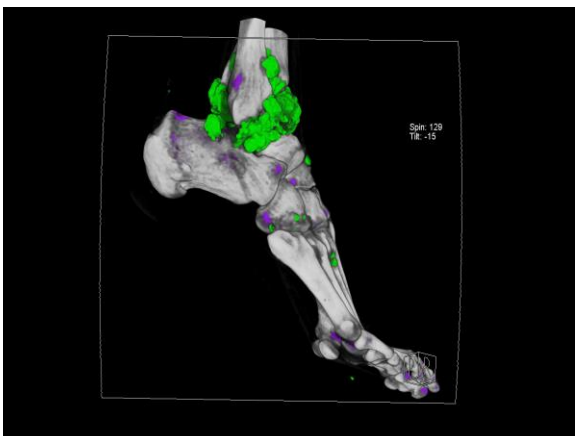
- Patient presents with hot, painful, inflamed joint
  - Causes: Gout, pseudogout, BCP or infection ?
- Treatments vary considerably
- Diagnosis made clinically
  - Speed of onset, severity of pain, inflammation, location
  - Hyperuricemia
- Definitive diagnosis
  - aspiration of joint fluid or tophi, polarized light micropscopy
  - 50% of aspirations non-diagnostic
- Great need for non-invasive diagnostic methods


Plain lateral radiograph


High density material in soft tissues within and surrounding joints consistent with tophaceous deposits




Spin: 100
Tilt: -14


Spin: 120
Tilt: -15


A L

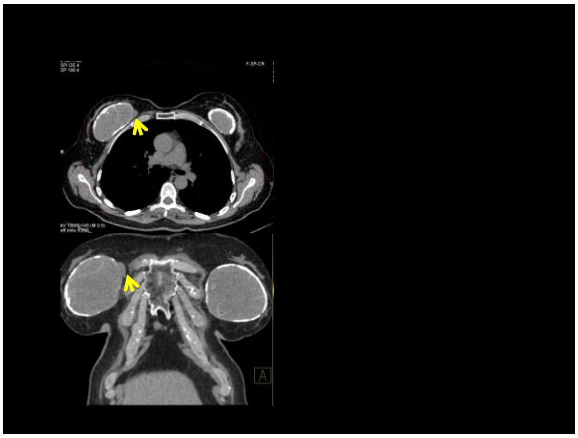
Disease Quantitation

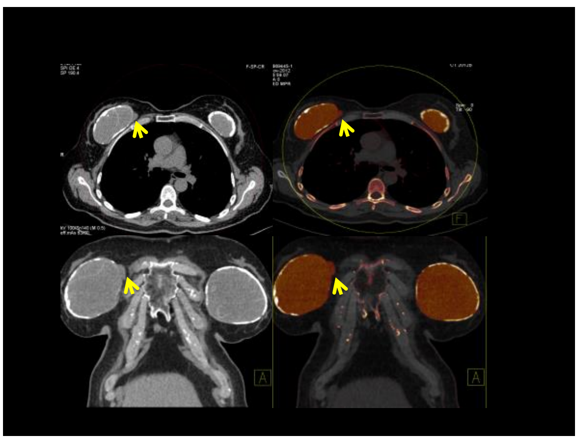
- Allow accurate assessment of disease burden (in terms of crystal volume)
- Allows pre and post treatment comparisons to identify non-responders early and alter their treatment course
- Provides definitive outcome measures for therapeutic regimens

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

Detection of Silicone Breast Implant Leaks

- Silicone can be taken up into surrounding tissues and lymph nodes and cause autoimmune illness
- FDA allowed silicone breast implants to return to the market, but recommended ANNUAL cross-sectional imaging to evaluate for leakage
- MRI is the only FDA-cleared cross-sectional technique for this application
- It is cost-prohibitive for most patients and few undergo surveillance imaging





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Automated Bone Removal in CT Angiography

- CT angiography is a minimally invasive technique to determine location, size, and patency of arteries and veins
- It has all but replaced invasive (catheter-based) angiography for diagnostic purposes
- A single exam can produce 100's to 1000's of images for interpretation
- Overlying bony anatomy interferes with useful visualization techniques (eg MIP and VRT)
- Manual or semi-automated bone removal can be labor intensive and/or operator dependent

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Perfused Blood Volume (Blood Pool Imaging)

- Assessment of blood distribution with a measurement made at a single time point
  - Perfusion measurements require temporal measurements
- Quantitative assessment of perfused blood volume shown to serve as a surrogate marker for ischemia/infarct and to correlate with direct measures of perfusion and flow

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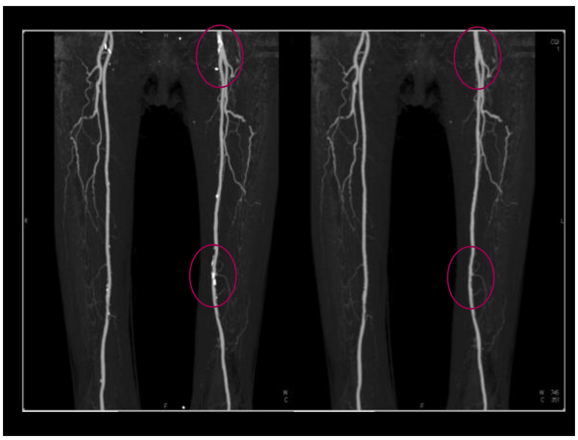
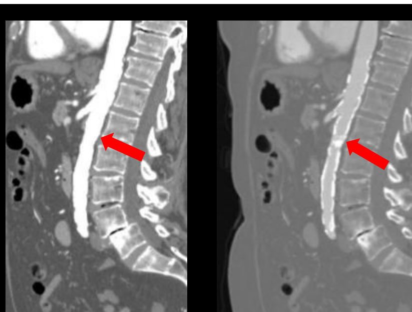
Plaque Removal

- Bright calcified plaques mask less-bright iodine-filled lumens, especially in MIP and VRT images
- Presence of significant calcifications can make CT angiogram uninterruptable, leading to the need for invasive diagnostic procedures
- Identification and digital suppression of calcium signal can preserve diagnostic value of CT angiography





Heavily calcified atheromatous plaque
with high grade stenosis of the aorta is difficult to
see on routine windows (left).
Need to use wide window settings (right).

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

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

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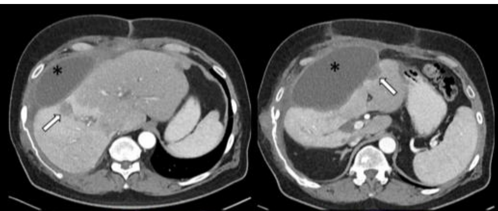
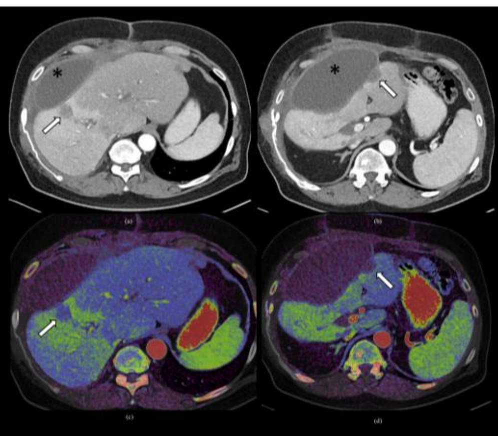
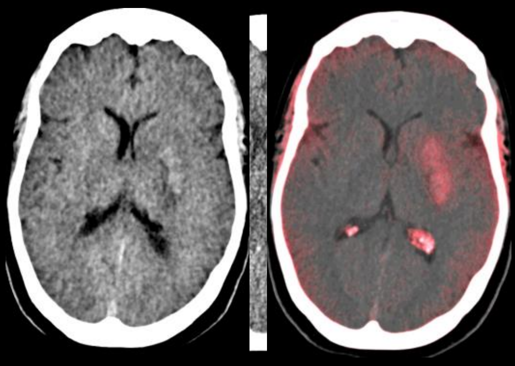
Virtual Noncontrast Images:

- Many diagnostic tasks require injection or ingestion of iodinated contrast media or barium
- Scans performed without contrast media not routinely included in most contrast-enhanced exams
- Sometimes, unexpected findings (e.g. modestly enhancing renal masses) are un-interpretable without having a non-contrast scan for comparison
- Identification and digital suppression of iodine signal can create a perfectly registered "virtual" non-contrast scan







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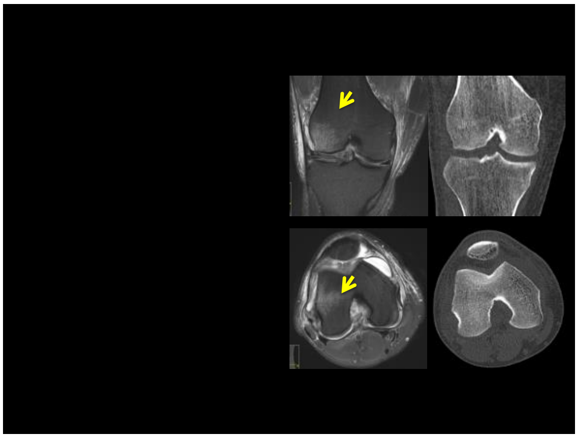
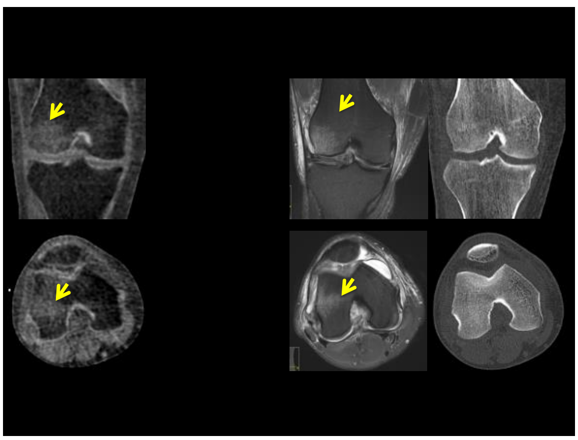
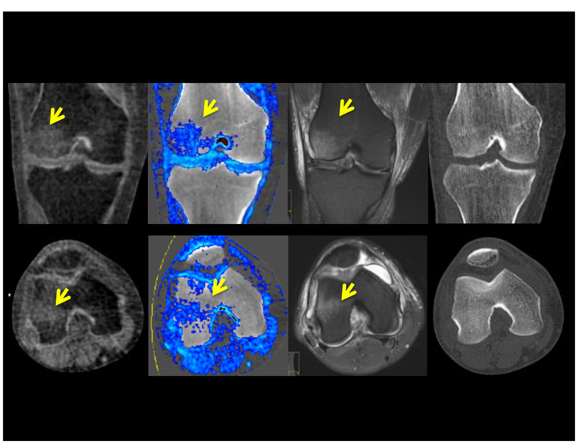
Virtual Non-Calcium Images:

- Traumatic or oncologic bone lesions (bruising, edema, bone marrow lesions) cannot be appreciated on CT in the presence of bright calcium signal
- These lesions can point to severity of joint injury, occult fractures, or oncogenic bone lesions
- Identification and digital suppression of calcium signal can allow appreciation of these findings, previously observed only with MRI







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Summary

- Multi-energy CT is a relatively recent clinical tool
  - Brief availability in 1980s
  - Reappearance in 2006
- Now commer…
  …es, gout, silicone)
- …ology continues to improve, more (and more quantitative) applications can be expected

Multi-energy CT is here to stay

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Thank you

Mayo Clinic CT Clinical Innovation Center

http://mayoresearch.mayo.edu/mayo/research/ctcic