Kidney Stone Diagnosis and Management

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Disclosures

• MGH has research agreement
  – GE Health Care
  – Siemens Medical Systems
Clinical Perspective

- Urolithiasis has a **life time risk of 10-15%**
- It has a high **relapse rate (50% in 5-10 yrs and 75% in 20 yrs)**
- Affects Men more than women
- **Common clinical presentation** – Acute flank pain and hematuria

MDCT in Urolithiasis

- Unenhanced CT - Initial investigation of choice in suspected urolithiasis
  - 22% of all CT performed in the ER for acute abdomen pain

- **Highly accurate test (Sensitivity = 95-98% & Specificity = 96-100%)**
  - Detects other causes of acute flank pain

- Identification of ureterolithiasis at imaging altered management in nearly 55%–60% of patients suspected of having acute renal colic.

- Reveals associated abnormalities like congenital abnormalities, infections and neoplasms

# Stone Types

<table>
<thead>
<tr>
<th>Composition</th>
<th>Occurrence</th>
<th>On KUB</th>
<th>On CT</th>
<th>Radioopacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium oxalate monohydrate &amp; dehydrate (COM) &amp; COD</td>
<td>40-60% Radio-opaque</td>
<td>Radio-opaque</td>
<td>Radio-opaque</td>
<td>20-60% Radio-opaque</td>
</tr>
<tr>
<td>Hydroxyapatite (Calcium phosphate)</td>
<td>20-60% Radio-opaque</td>
<td>Radio-opaque</td>
<td>Radio-opaque</td>
<td>2-4% Radio-opaque</td>
</tr>
<tr>
<td>Uric Acid</td>
<td>Radio-opaque</td>
<td>Radio-lucent</td>
<td>5-10% Radio-opaque</td>
<td></td>
</tr>
<tr>
<td>Struvite</td>
<td>5-15% Radio-opaque</td>
<td>Radio-opaque</td>
<td>Radio-opaque</td>
<td></td>
</tr>
<tr>
<td>Cystine</td>
<td>1-2.5% Mildly Opaque</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Composition On KUB On CT*
MDCT Technique

- **Scan Coverage** - Upper pole of kidneys to the base of the bladder
- **Patient preparation** - Bladder distension to visualize stones within the distal ureter

**Slice thickness** – 3-5 mm

**Pitch** - 1 - 1.6

**Coronal Reformations**

(2.5 - 3mm)
Urolithiasis - CT Diagnostic Signs

Virtually all stones are radio-opaque on CT (>200HU)

Primary sign of Ureterolithiasis
Stone in the ureter (target sign) with proximal hydroureter

Stones radiolucent on CT - Pure matrix stones and stones made of pure Indinavir (Indinavir - Protease inhibitor used in the treatment of HIV)
Value of Coronal Reformations

- Improved detection of stones unrecognized on axial images
- Improved detection of small ureteral and renal calculi at poles
- Phleboliths and calcified vascular plaques from urinary stones
- Enhances radiologist confidence
- Benefits the urologists in treatment decision

Factors Influencing Treatment Decision

Urologic intervention is influenced by 3 crucial factors

- Stone size/location
- Stone Composition
- Patient Symptoms

Presence of obstruction is not the primary factor considered for urologic intervention

**Stone Burden Assessment**

- Stone burden (stone size and volume) determines the type of procedure
- **ESWL or Ureteroscopy is performed for stones <1cm**
- **PCNL for stones >1.5cm**

**Stone Size**

- Accurate stone size measurement is paramount to plan treatment options
- The ideal method for accurate measurement on CT is to measure using **bone window settings (1250 X 250) and magnification**

Eisner BH et al. J Urol 2009
Stones > 6mm & <15mm
(6-9 mm ureteral stone 60-25% pass)
Stone location predicts outcome
Upper=48%, mid=60%, lower 75-79%
likely to pass spontaneously

Stone < 5mm
(98% for stones < or = 4mm pass spontaneously)

Medical Expulsive therapy
(Alpha blockers)
Intervene for unremitting pain, nausea, fever, failure to passage on medical therapy

Stones > 6mm & <15mm
(6-9 mm ureteral stone 60-25% pass)
Stone location predicts outcome
Upper=48%, mid=60%, lower 75-79%
likely to pass spontaneously

• Extracorporeal Shockwave lithotripsy (ESWL)
• Ureteroscopic lithotripsy (upper ureter or larger stone)

Stone >15mm or Staghorn Calculi

Percutaneous Nephrolithotomy (PCNL)
• Coll DM et al. AJR 2002.
Stone Volumetry

Threshold based CAD Algorithms or manual semi-automated methods

- Linear measurement not suitable in irregularly contoured stones like stag horn calculi
- Measuring the stone volume eliminates this problem
- Total stone volume is an appropriate measure of stone burden

- Demehri S et al. AJR 2012.
- Singh Ak et al. RSNA 2010.
# ESWL Failure: Multivariate CT characteristics

<table>
<thead>
<tr>
<th>Independent Variables (Dependent Variable = failure rate)</th>
<th>Area-Under Curve (AUC)</th>
<th>Cut-off value</th>
<th>Sensitivity; Specificity (%)</th>
<th>95% Confidence Interval (CI)</th>
<th>P=value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Volume CAD</td>
<td>0.895</td>
<td>&gt;712.54 mm³</td>
<td>80;80</td>
<td>0.745-0.964</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>Stone Volume-Products</td>
<td>0.872</td>
<td>&gt;564.75 mm³</td>
<td>88;73</td>
<td>0.728-0.956</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>Maximum Stone Size</td>
<td>0.839</td>
<td>&gt;8.89mm</td>
<td>96;60</td>
<td>0.688-0.936</td>
<td>P&lt;0.0001</td>
</tr>
<tr>
<td>Number of Stones</td>
<td>0.755</td>
<td>&gt;2</td>
<td>52;86</td>
<td>0.593-0.877</td>
<td>P=0.0002</td>
</tr>
<tr>
<td>Mean Stone Size</td>
<td>0.735</td>
<td>&gt;6.25mm</td>
<td>92;46.7</td>
<td>0.571-0.861</td>
<td>P=0.0002</td>
</tr>
<tr>
<td>Age</td>
<td>0.524</td>
<td>&lt;50y</td>
<td>96;33</td>
<td>0.360-0.684</td>
<td>P=8267</td>
</tr>
</tbody>
</table>

Overall model fit (Chi square) = 21.818; p = 0.0006

Singh Ak et al. RSNA 2010.
Stone Composition & Treatment Decisions

- **<400 HU**
  - Uric Acid Stone
  - Medical Management
  - Allopurinol
  - Treatment of Hyperuricemia

- **> 500 HU**
  - <1000 HU (Struvite)
    - ESWL
  - >1000 HU (Brushite, Cystine, COM)
    - Ureteroscopy
    - PCNL

Parker BD et al. Urology 2004
MDCT and Stone Composition

Stone composition can be determined using HU

**CT Attenuation values** – 64-77% accuracy in determination of stone composition, is not robust and reliable

<table>
<thead>
<tr>
<th>Stone Composition</th>
<th>Attenuation value at 120kVp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uric Acid</td>
<td>200-450 HU</td>
</tr>
<tr>
<td>Struvite</td>
<td>600-900 HU</td>
</tr>
<tr>
<td>Cystine</td>
<td>600-1100 HU</td>
</tr>
<tr>
<td>Calcium Phosphate</td>
<td>1200-1600 HU</td>
</tr>
<tr>
<td>COM and Brushite</td>
<td>1700-2800 HU</td>
</tr>
</tbody>
</table>

• Stone composition also effects the efficacy of ESWL (Brushite, cystine and COM stones are hard and resistant, while struvite stones usually fragment easily)

Dretler SP. J Endourol 2001
Motley G et al. Urol 2001
Eisner BH et al. J Urol 2009
KulkarniN et al. JCAT (in-press)
### DECT: Stone composition

<table>
<thead>
<tr>
<th>Element composition</th>
<th>Uric Acid Stone</th>
<th>Non uric acid stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Elements</td>
<td>H, C, N, O</td>
<td>Heavy Elements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(P, Ca, S)</td>
</tr>
<tr>
<td>Attenuation at 80 kVp</td>
<td>Lower HU</td>
<td>Higher HU</td>
</tr>
<tr>
<td>Attenuation at 140 kVp</td>
<td>Higher HU</td>
<td>Lower HU</td>
</tr>
</tbody>
</table>

#### Attenuation Values

- **Calcium**
  - **80kV**: 710 HU
  - **140kV**: 480 HU

- **Uric Acid**
  - **80kV**: 290 HU
  - **140kV**: 315 HU
Renal Stone Composition: 11 studies (dsDECT=8 & ssDECT=3)

- Uric Acid vs. Non UA stone differentiation possible
  - Phantom and humans 100%
  - Reliable for stones 3 mm and above

- Non-UA subtype of pure composition possible in phantom and in humans
  - mixed composition stones difficult to characterize

Stone Fragility in Guiding Treatment

• CT helps predict stone fragility and susceptibility to lithotripsy
• Stones which are heterogeneous are more fragile than homogenous stones which are more resistant to ESWL
**Stone Precursor-Randall’s Plaque**

- **Randall’s Plaque** - Calcium salt deposits in the tip of renal papilla of patients with nephrolithiasis and are potential sites for calculus formation
- These stone bearing papillae appear denser on non-contrast CT and represent Randall’s plaque on endoscopy
- MDCT can help select patients at high-risk for stone formation, who may undergo appropriate medical management to halt the formation of stones

MDCT in Planning Intervention

- Simple trigonometry on CT of the patients with complex stones could help endourologists in planning renal access.
- CT also helps in planning surgical interventions by identifying the location of the posterior calyx thus guiding fluoroscopic procedures like percutaneous nephrolithotomy.
Calculi with attenuation > 300 HU are radio-opaque & are followed up by Abdominal Radiograph

Calculi with attenuation < 200 HU are radiolucent & hence followed up by CT

CT attenuation is a good predictor of utility of radiography in routine follow up

In patients managed medically,
Pre Treatment

Significant Stone Burden

Post Treatment

Residual Stone Burden though significantly reduced

Significant stone burden necessitates further treatment
Differentiation between stent and stone is vital in post surgical follow up.

Stents and stones have the same CT appearance on abdominal window.

Bone window allows visual distinction between the stent and the stone which is accounted for by differences in pixel density.

Tanricut C et al. Urology 2004
MDCT and Radiation Dose

• A key concern for repeated CT examinations in recurrent stone disease.

• The effective radiation dose during unenhanced CT
  
  2.8 to 13.1 mSv for men / 4.5 to 18 mSv for women

• Techniques for Reduction of Radiation dose

  - Limit scanning area (not typical Abd+Pelvis exam)

  - Increase in axial slice thickness to 5mm from 1-3 mm
    and include 2.5-3 mm coronal reconstructions

  - Lower dose CT exam (↑ noise index, ↓ kVp, ↑ pitch)
Strategies for Dose Reduction

Limit Scanning area

Increase slice thickness
Include coronal reformations

DLP 1000 mGy-cm

Low kVp

Low mAs

DLP 200 mGy-cm

Total Dose Reduction by 40-70% from Standard dose
Ultra-low dose approaches

Renal stone

Initial scan – Standard dose CT (low mAs)

Follow up scan – ultra-low dose CT

<table>
<thead>
<tr>
<th>WT</th>
<th>kVp</th>
<th>mA</th>
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<tbody>
<tr>
<td>Low dose CT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;200 lbs</td>
<td>80</td>
<td>75-150</td>
</tr>
<tr>
<td>&gt; 200 lbs</td>
<td>100</td>
<td>75-150</td>
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</table>
Ultra-low dose approaches

177 lbs

280 lbs
18 DEC 2007

DLP 388
5.82

22 DEC 2008

DLP 184
2.76

53%
## Radiation Dose-ULD Stone CT

<table>
<thead>
<tr>
<th>Wt Category</th>
<th>Std dose CT</th>
<th>ULD CT</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>CTDI</td>
<td>mSv</td>
</tr>
<tr>
<td>Over all</td>
<td>11.4</td>
<td>8.8</td>
</tr>
<tr>
<td>&lt; 200 lbs</td>
<td>10.6</td>
<td>8.6</td>
</tr>
<tr>
<td>&gt; 200 lbs</td>
<td>15.4</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Kulkarni N M et al. Radiology 2012
More aggressive dose reduction

2 View KUB = 0.6 – 1.2 mSv

CT KUB = < 1 mSv

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Abdomen CT</th>
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</thead>
<tbody>
<tr>
<td>Marin D</td>
<td>Radiology. 2010</td>
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<tr>
<td>Prakash P</td>
<td>Invest Radiol. 2010</td>
<td></td>
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<td>Sagara Y</td>
<td>AJR Am J Roentgenol. 2010</td>
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<td>Singh S</td>
<td>Radiology. 2010</td>
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<td>May MS</td>
<td>Invest Radiol. 2011</td>
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<td>Schindera ST</td>
<td>Radiology. 2011</td>
<td></td>
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<tr>
<td>Martinsen AC</td>
<td>Eur J Radiol. 2011</td>
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<tr>
<td>Vorona GA</td>
<td>Pediatr Radiol. 2011</td>
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</table>
Current Imaging Strategy

The scope of imaging has extended beyond the mere detection of stone and its location.

The current strategy is to determine the stone composition, its fragility and quantification which has great implications in treatment planning.
Summary Points

• MDCT with multiplanar reformations is accurate in stone assessment.

• The qualitative assessment by CT influences management by dictating treatment options like ESWL.

• Spectral imaging and CAD is emerging for stone composition/Quantitation.

• Various strategies for radiation dose reduction in imaging of urolithiasis achieving accurate diagnosis and reduced radiation dose delivery.

• New reconstruction algorithms (ASIR) is promising in dose reduction.
References

<table>
<thead>
<tr>
<th>Journal/Year</th>
<th>DECT Technique</th>
<th># Stones</th>
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Dual-Energy CT for Stone Composition

- **Dual Source CT**: By operating the two tubes at different energies (80 & 140 kVp) it is effective in tissue material composition.

- **Gem stone spectral imaging (single source DECT)** - is a recent DE CT operated on rapid kVp switching is also available for tissue characterization/stone composition.

Post Processing - **DSDCT**

- **High and low kVp**
- **Two X-ray tube**

- **80 kV**
- **140 kV**

- **Uric acid stones - Red**
- **Non Uric acid stones - Blue**

(Syngo VA 11; Siemens)

3 material decomposition algorithm
Post Processing - SDCT

High and low kVp
Rapid kV twitching

MD Water
MD Iodine

Uric Acid stone = MD Water +, MD Iodine –
Non-Uric Acid stone = MD Water +, MD Iodine +

Effective Z Image

Kidney Stone Differentiation

Effective z number – scatter plot
Dual-Energy CT for Stone Composition

Phantom Model – Uric Acid vs Non uric Acid

**DSDCT**
- 65 stones (Size Range: 2-18mm)

**SDCT**
- 35 stones (Size range: 3-19mm)

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;3mm</td>
<td>&gt;3mm</td>
</tr>
<tr>
<td><strong>DSDCT</strong> (UA -16, Non UA =49)</td>
<td>8/8 (100%)</td>
<td>57/57 (100%)</td>
</tr>
<tr>
<td><strong>SDCT</strong> (UA -6, Non UA =29)</td>
<td>2/2 (100%)</td>
<td>33/33 (100%)</td>
</tr>
</tbody>
</table>

Dual-Energy CT for Stone Composition

65 stones (Size Range: 2-18mm) 35 stones (Size range: 3-19mm)
## Dual-Energy CT for Stone Composition

### Patients – Uric Acid vs Non uric Acid

<table>
<thead>
<tr>
<th></th>
<th>DSDCT</th>
<th>SDCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stones</td>
<td>37 stones</td>
<td>49 stones</td>
</tr>
<tr>
<td>Mean size</td>
<td>Mean size-6mm, Range 2-24mm</td>
<td>(Mean size-6.8mm, Range 1.2-28mm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CT</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA</td>
<td>7</td>
<td>UA</td>
</tr>
<tr>
<td>Non UA</td>
<td>23</td>
<td>Non UA</td>
</tr>
<tr>
<td>Not Identified</td>
<td>7</td>
<td>Not Identified</td>
</tr>
</tbody>
</table>

**Final confirmation**

- 9/18 patients
- 20 Stones (6 uric acid & 14 non uric acid)

- 3/17 patients
- 8 Stones (All calcium oxalate)
## Dual-Energy CT for Stone Composition

### Phantom Model – Differentiation of Non uric Acid

<table>
<thead>
<tr>
<th>Red</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.15</td>
<td>Uric Acid, Struvite, Brushite, COM, Cystiene</td>
</tr>
<tr>
<td>1.30</td>
<td>Uric acid, Struvite, Cystine</td>
</tr>
<tr>
<td>1.45</td>
<td>Uric acid, Struvite, Brushite, COM</td>
</tr>
<tr>
<td>1.60</td>
<td>Uric acid, Struvite, Brushite, COM, Cystiene</td>
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<table>
<thead>
<tr>
<th>Calculated Effective z</th>
<th>Effective Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uric Acid</td>
<td>6.92</td>
</tr>
<tr>
<td>Struvite</td>
<td>9.72</td>
</tr>
<tr>
<td>Cystine</td>
<td>11.07</td>
</tr>
<tr>
<td>COM</td>
<td>14.37</td>
</tr>
</tbody>
</table>

90% Cystine stones (9/10) / 84.2% Struvite stones (11/13)
Strategies for Dose Reduction - Coverage Area

- From top of diaphragm to lower border of pubic symphysis
- From Top of kidneys to base of urinary bladder

Restrict Scanning Area

Dose Reduction by 15-20%

Targeted scans focused to area of interest can be performed for follow up CT exams
Strategies for Dose Reduction - Slice Thickness

Increase Slice thickness from 1-3mm to 5mm and include 2.5-3mm Coronal Reformations

Dose Reduction by 20-40%
Strategies for Dose Reduction
Role of Low kVp - Exam based on Body Weight

Dose = \sqrt{kVp}

140 kV (> 250 lbs)

120 kV (141-249 lbs)

100/80 kV (<140 lbs)

20% reduction

20% reduction

20% reduction

Total 40 % Dose Reduction
Strategies for Dose Reduction - Increase in Noise Index/ reference mAs (100-180)

Noise Index -15

15-20% reduction

Noise Index -20

15-20% reduction

Noise Index -30

Total 30-40 % Dose Reduction
# MDCT Protocol Modifications

<table>
<thead>
<tr>
<th>GE</th>
<th>WT</th>
<th>Slice Th</th>
<th>mA</th>
<th>NI</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/64-MDCT</td>
<td>&lt;300</td>
<td>5</td>
<td>150-450</td>
<td>25 - I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 - F</td>
</tr>
<tr>
<td></td>
<td>&gt;300</td>
<td>5</td>
<td>150-450</td>
<td>25 - I</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 - F</td>
</tr>
</tbody>
</table>

- **NI**: Noise index
- **I**: Initial scan
- **F**: Follow up scan

<table>
<thead>
<tr>
<th>Siemens</th>
<th>WT</th>
<th>Ref mA</th>
<th>SI Thick</th>
<th>DC</th>
<th>Pitch</th>
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</thead>
<tbody>
<tr>
<td>16-64</td>
<td>All wt group</td>
<td>100-160</td>
<td>5</td>
<td>24x1.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

**kV (100-120)**
MDCT Protocol Modifications

Review Phase (116 lbs)
CTDI- 11.5

CTDI- 4.22
Monitoring Phase (114 lbs)

↓61%
Adaptive Statistical Iterative Reconstruction (ASIR)

- Noise reduction reconstruction method to improve the signal-to-noise
- Relies on the accurate modeling of the distribution of noise in the acquired data

- MGH Experience (GE HD 750) 65 patients studied so far
  - Radiation dose reduction achieved (25-81%)