Imaging urinary stones: From the ER to the OR and beyond

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Disclosures & Off-label applications

- CZ: No corporate disclosures
- BC: Consultant/Instructor: ADVA-Tec, Bard Medical, Boston Scientific, Cook Medical, Olympus Medical, Urotech
- No off-label applications will be discussed
Objectives

- Review diagnostic performance of imaging tests - Strengths and Limitations
- Review dual energy CT (DECT) applications
- Radiation dose - Fear and Reality

Clinical scope

Urinary stones are common

- 3-15% of population experience renal colic
- 1.7% of adult ER visits 2000-8 in USA
- Prevalence has increased 37% over 20 years
- Estimated societal cost US$ 5.3B in 2000, increasing*
- Stones frequently recur: 50% at 10 yrs, 75% at 20 yrs

*Saigal CS *Kidney International* 2005
Acute symptoms
Utility of MDCT - stone detection

- Stone burden
- Presence of obstruction
- Need for urgent intervention
- Alternate diagnosis - 24%
- Stone characterization
- Guide imaging follow-up
- CT scout sensitivity 42-52%
- ACR Appropriateness level 8
MDCT technique
recon plane

- AX plane underestimates size by 13-21%, if stone coronally oriented
- COR plane improves conspicuity of stones <5mm
- dual plane recon complementary
- scan prone

Non acute & surveillance
Radiography

- Follow up or new symptoms in stone disease visible on prior CR or 80kVp CT topogram/scout
- Sensitivity 57%, specificity 71%
  Sensitivity improves to 73% when prior CT available*
- Low dose, E= 0.6-1.1 mSv
- Limitations: cystine, uric acid, indinavir, pure matrix
- ACR appropriateness level 6

Niemann T, AJR 2008
Kulkarni N, Radiology 2012
*Renard-Penna R, World J Urol 2015
Non acute & surveillance
Ultrasound for ureteric stones

Advantages:
- Primary tool in pediatrics and pregnancy
- up to 96% detection of ureteric stones if age <35 and BMI <24
- Sensitivity better for distal location (94%) than prox (25%) or mid ureter (7%)
- Twinkle artifact - sens 83% PPV 94%
- ACR Appropriateness level 6

Caveats:
- Operator dependent
- Obesity
- Distended bladder or endovaginal scan required to visualize distal stones
- May miss or overestimate stone size when <5mm
- May underestimate stone burden

Pichler R, BJU 2011
Ray AA, J Urol 2010
Israel G, Ultrasound Quart 2012
Non acute & surveillance
Radiography + Ultrasound combined

- Sensitivity 89%
- Specificity 100%
- PPV 100%
- NPV 81%
- ACR appropriateness level 7

Can CT predict Rx response?
CT attenuation + morphology

- Attenuation values useful:
  uric acid, struvite <1000HU

- SWL stone free rates:
  100% if <500 HU*
  90% if <750 HU**
  86% if 500-1000 HU*
  54% if >1000 HU*

- Favorable: internal heterogeneity
- Unfavorable: skin-stone distance (SSD) >11cm, HU >900 correlate with increased risk of SWL failure***

**Gupta NP, BJU Int 2005
***Weisenthal JD, J Urology 2011
In-vivo chemical characterization
Dual energy MDCT

- Software based material decomposition analysis
- DECT @ 80/140 kVp accurate in differentiating uric acid (UA) from non-UA (cysteine, oxalate, apatite)
- performance improved in large patients

Wen CC, Urol Clin N Am 2007
Virtual non-enhanced imaging
VNE vs. True NE

Gen 2 (Flash)
- improved image quality, still inferior to True NE images
- sens 55% ≤3mm on nephrographic and 38% on pyelographic

Gen 2 VNE still routinely misses stones ≤3mm

Gen 1 (Definition)
- limited by small FOV, high noise and low resolution
- 74.3% of stones detected on VNE from nephrographic phase
- sens 38% for <3mm, 64% for 3-4mm, 83% for 5-6mm, 100% if >7mm

Lundin M, Acta Radiologica 2012
Dual energy CT in patients with acute abdomen: is it possible for virtual non-enhanced images to replace true non-enhanced images?

A. Lan Im - Young Hwan Lee - Dong Ho Bang - Kwon Ho Yoon - Sang Hyun Park

- retrospective, VNE and TNE DECT in 202 patients
- Gen2 scanner (Flash)
- 33 - 47% dose reduction if only VNE performed
- True NE better sensitivity for stones <3mm
- moderate to severe artifacts in 20 patients
Where is the calcification on CT?
How precise is CT for localization

- small papillary-tip calcifications are common
- precise localization by CT challenging in absence of hydronephrosis
- etiology: calcified papillary plugs, NOT Randall plaques

![Stone former vs non stone former](image)

- Compared radiography, CT to flex nephroscope in 36 patients after PNL
- Helical scanner, 5mm and 2.5mm axial recons
- 90.2% of calices inspected endoscopically
- Radiography sensitivity 46%/spec 81.8%
- CT sensitivity 100% for residual stones
- CT false-positive 12.2%
- CT accuracy 87.8%

Krambeck AE, *J Urol* 2013

Sensitivity of Noncontrast Helical Computerized Tomography and Plain Film Radiography Compared to Flexible Nephroscopy for Detecting Residual Fragments After Percutaneous Nephrostolithotomy

Margaret S. Pearle, Lori M. Watamull and Mary A. Mulligan

From the Departments of Urology and Radiology, University of Texas Southwestern Medical Center, Dallas, Texas

Pearl MS, *J Urology* 1999
Nephrocalcinosis: re-defined in the era of endourology

Nicole L. Miller · Mitchell R. Humphreys · Fredric L. Coe · Andrew P. Evan · Sharon B. Bledsoe · Shelly E. Helde · James E. Langman

Distal RTA compared 16-MDCT and ureteroscopy in predicting exact anatomic location of calculi; URS = “gold standard”

Mean delay of 46 days between CT and URS

60% pelvicalyceal, 40% parenchymal or papillary

NSD in size by location

How accurate is unenhanced multidetector-row CT (MDCT) for localization of renal calculi?

Stefan Goetschi, Martin Umbert, Stephan Ullrich, Michael Glenck, Stefan Suter, Dominik Weishaupt

1 Institute of Radiology, University Hospital, Winterthurerstrasse 427, 8091 Zürich, Switzerland
2 Urology Clinic, Department of Surgery, University Hospital, Winterthurerstrasse 427, 8091 Zürich, Switzerland

compared 16-MDCT and ureteroscopy in predicting exact anatomic location of calculi; URS = “gold standard”
- All calyceal stones:
  Sens 76-87%
  Spec 41-66%

- Calyceal <4mm:
  Sens 34-66%
  Spec 43-66%

- Calyceal ≥4mm:
  Sens 90-94%
  Spec 50-100%

- **Papillary calcifications of any size:**
  accuracy 18-58%

- **Agreement (kappa):**
  calyceal 0.54-0.67
  parenchymal 0.23-0.42

Can CT predict stone formation?

- Randall plaque theory of stone formation
- sub-urothelial calcium deposits or papillary duct plugs*
- papillary-tip micro calcifications on CT

Coe FL, Urol Res 2010
12/362 (3.3%) developed stones after 7 years
43HU threshold optimal in ROC analysis
53% with papillary attenuation >43HU developed stones
odds ratio 91.05
- 187 with calcium stone confirmed on CT
- post-Rx stone free confirmation by CT
- mean follow-up 5 years
- papillary attenuation >43HU associated with RR=8.7 stone recurrence
- RR =11.2 if ≥3 papillae >43HU
Radiation risk: Fear and Facts

- per capita annual effective dose from CT:*  
  USA   0.5 mSv in 1982
  3.0 mSv in 2006 (6x)  
  Canada 0.19 mSv in 1991
  0.74 mSv in 2006 (3.9x)  
- 1.8 million CT KUB studies in US 2005-7  
- ED CT use in renal colic increased 7-12x  
  1996-2008**  
- 79% evaluated for renal colic in ED underwent ≥2 CT, with median dose of 14.5 mSv***

*Chen J, J Radiol Prot 2010  
**Dalziel JD, Emerg Med J 2013  
- Natural background dose:**
  Vancouver 1.2-1.3 mSv/yr
  BC 1.2-7.9 mSv/yr
  Canada 1.8 mSv/yr

- LAR cancer death estimate from a single CT:
  10 mSv = 0.05% adult***
  = 5:10,000

- LAR death estimate children/adolescents
  10 mSv = 0.1-0.15%***

**nuclearsafety.gc.ca and triumf.ca
***Bosch de Basea M, *J Radiol Prot* 2015

- considerations: based on 2005-06 survey data
  25% sites using scanners >5 years age
  mean ED 15.8-16.1 mSv

*Brenner DJ, *NEJM* 2007
Acute symptoms
Multidetector CT performance

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
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<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E &gt;3 mSv</td>
<td>0.94 - 1.00</td>
<td>0.97 - 1.00</td>
</tr>
<tr>
<td>Low dose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E &lt;3 mSv BMI &lt;30</td>
<td>0.97</td>
<td>0.95 - 1.0</td>
</tr>
<tr>
<td>Low dose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E &lt;3 mSv BMI &gt;30</td>
<td>0.5</td>
<td>0.89</td>
</tr>
<tr>
<td>Ultra low dose</td>
<td></td>
<td></td>
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<tr>
<td>E &lt;1 mSv</td>
<td>0.73-0.97</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Abramson S, AJR 2000
Kluner C, JCAT 2006

Radiation Dose Index of Renal Colic Protocol CT Studies in the United States: A Report from the American College of Radiology National Radiology Data Registry

- Registry of 49903 renal colic protocol CT exams from 93 centres, 2011-2013
- overall mean dose 746 mGy.cm (E= 11.2 mSv)
- institutional mean E=4.6 - 22.5 mSv
- 2% exams E <3mSv
- 0.2% exams E <2mSv

Lukasiewicz A, Radiology 2014
Comparison of Abdominal radiography and Non-contrast Ultralow dose CT for Kidney Stones: CANUCKS trial

DR PATRICK MCLAUGHLIN FFR (RCSI) FRCPC
VANCOUVER GENERAL HOSPITAL
UNIVERSITY OF BRITISH COLUMBIA, CANADA

Datasets were randomized, anonymized and blindly reviewed.

**Image Analysis**

**Abdominal Radiograph**
1. Ureteric Calculi
   - Size
2. Renal Calculi

**Ultralow Dose CT**
1. Ureteric Calculi
   - Size
2. Renal Calculi

GOLD STANDARD
CONVENTIONAL DOSE CT

Excel v15.16 (Microsoft Corporation, Redmond, VA)
Prism v5 (Graphpad, La Jolla, CA)

**Radiation Exposure**

**Abdominal Radiography**
- 0.54±0.11 mSv

**Ultralow dose CT**
- 0.28±0.08 mSv
  - CTDIvol: 0.47±0.26mGy
  - DLP: 20±12mGy.cm

**Conventional CT**
- 6.06±3.08 mSv
  - CTDIvol: 9.1±4.1mGy
  - DLP: 404±205mGy.cm
Ultralow dose CT

Diagnostic performance
- Sensitivity: 95%
- Specificity: 98%
- PPV: 98%
- NPV: 95%

Both measure ≤2mm

Abdominal Radiograph 0.6mSv

Conventional CT 5.3mSv

Ultralow Dose CT 0.25mSv
Summary strengths

- CT preferred imaging modality for acutely symptomatic non-pregnant patient
- DECT offers a multi-parametric assessment of stone disease (burden, composition, architecture, future risk)
- US +/- CR continue to be std of care for routine follow up post Rx/surveillance in most patients
- Sub mSv CT is a feasible but quality degraded imaging tool for stone assessment in selected low BMI
Summary

limitations

- VNE images from current dual energy CT are suboptimal to TNE and may miss stones ≤3mm
- Clinical VNE data from new systems limited
- CT may be inaccurate in precise localization of papillary tip calcifications & small calyces stones - consider URS
- Sub mSv CT is not applicable for BMI >30
- Don’t rely purely on US for Rx decisions
Is pre-operative imaging essential prior to ureteric stone surgery?
FR Youssef, BA Wilkinson, KJ Hastie, and J Hall

• Patients prior to semi-rigid ureteroscopy
• 96 patients with stones 3-20 mm
• KUB or CT-KUB or both on day of surgery
• 13/96 patients (14%) were cancelled because no stones identified on pre-op imaging
  • 8/13 (62%) were confirmed by CT-KUB
• 1/7 patients have passed their ureteral stone—avoid unnecessary anesthetic and ureteroscopy
• Pre-op imaging prior to surgery (~24 hr) is highly recommended.


Is a contrast study really necessary prior to ureteroscopy?

<table>
<thead>
<tr>
<th>Table 2. Operative characteristics of the groups</th>
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<tbody>
<tr>
<td>IVP</td>
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<tr>
<td>-----------------------------------------------</td>
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<tr>
<td>No. patients (%)</td>
</tr>
<tr>
<td>Ureteral orifice dilatation*</td>
</tr>
<tr>
<td>Lithotripsy technique*</td>
</tr>
<tr>
<td>Ho:YAG laser</td>
</tr>
<tr>
<td>Operative time* (min)</td>
</tr>
<tr>
<td>Stone-free rate (%)</td>
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<tr>
<td>Complications (%)</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SD or number and percent. Group I, intravenous urography; group II, computed tomography; group III, computed tomography and intravenous urography; group IV, ultrasonography and abdominal plain film. Ho:YAG: holmium:YAG. *Statistically significant at P < 0.05. Kruskal-Wallis analysis of variance was used for intergroup comparisons of continuous variables (post hoc: Bonferroni), and the chi-square test was used for comparison of categorical variables.

Contrast study is NOT necessary prior to ureteroscopy
How much is a kidney worth? Cost-effectiveness of routine imaging after ureteroscopy to prevent silent obstruction.

Sutherland TN, Pearle MS, Lotan Y.

- STRicture—silent obstruction – loss of kidney function
- The costs and prevalence of lifetime complications associated with silent loss of 1 kidney were obtained from the renal donor transplant literature.
- Decision tree constructed re: cost of routinely imaging ALL patients after ureteroscopy vs selective imaging based on postoperative pain
- Cost for ALL patients: $5,326 vs $5,196 for selective imaging
- Assuming a 2% rate of silent obstruction, the cost per kidney saved would be $6,262.
- $130 more per patient justifies the additional modest cost to image ALL pts


Upper tract imaging after ureteroscopic holmium:YAG laser lithotripsy: when is it necessary?

Beiko DT, Beasley KA, Koka PK, Watterson JD, Nott L, Denstedt JD, Razvi H.

- 94 ureteroscopy cases
- Looking for postoperative upper tract obstruction following ureteroscopy
- 6 patients had hydronephrosis
  - 4 ureteral strictures—all had risk factors for stricture
  - 2 residual obstructing stones
- Routine postoperative imaging is not necessary in all patients undergoing uncomplicated ureteroscopy.
- Indications for imaging:
  - chronic stone impaction, significant ureteral trauma, pre-existing renal function impairment, endoscopic evidence of stricture and postoperative flank pain or fever.

Can J Urol. 2003 Dec;10(6):2062-7
Contemporary Imaging Practice Patterns Following Ureteroscopy for Stone Disease

Omar Mohamed, Chaparala Hemant, Monga Manoj, and Sivalingam

PMID: 25963170

Imaging following Ureteroscopy

- 322 urologists completed the questionnaire
- Years in practice (mean) 18 ± 10 years
- 82% respondents performed >5 years URS/year
- Routine imaging: 48% of urologists
  - U/S: 47%
  - KUB: 17%
  - CT: 4%
  - IVP: 2%
  - KUB + U/S: 30%

Why no imaging (vs imaging)?

- Concerned about costs (55% vs 25%)
- Radiation exposure (69% vs 44%)
- Diagnostic inaccuracy of US (57% vs 44%)
- No imaging: Less likely to have completed endourology fellowship (7% vs 23%, $p \leq 0.0001$)
- Predictors of imaging:
  - Postoperative pain and fever (median 5, IQR 1),
  - Residual stones (median 5, IQR 1),
  - Ureteral perforation (median 5, IQR 2),
  - Solitary kidney (median 4.5, IQR 2).

*J Endourol. 2015 Oct;29(10):1122-5*

AUA Guidelines

- From previous studies, it is clear that the incidence of post-operative obstruction in asymptomatic patients is decidedly low (Level C).
- Imaging all ureteroscopy patients to detect the rare case of silent obstruction is not cost-effective.
  - Would need 25 cases (without pain) to detect 1 silent obstruction
- Although seemingly a small price to pay to avoid loss of one renal unit, this need-to-treat value is hardly justifiable from a strictly economic viewpoint.
- Nonetheless, the Panel believes that the relatively low cost and lack of ionizing radiation associated with renal sonography justifies its use in routine follow-up of patients treated for ureteral calculi.
- Most obstruction due to stones—can see on KUB
First-in-human clinical trial of ultrasonic propulsion of kidney stones
Jonathan D. Harper MD, Bryan W. Cunitz MS, Barbrina Dunmire MS, Franklin C. Lee MD, Mathew D. Sorensen MD MS, Ryan S. Hsi MD, Jeff Thiel, Hunter Wessells MD, James E. Lingeman MD, Michael R. Bailey PhD

- repositioned stones in clinic (awake, no sedation) or during ureteroscopy (anesthetized)
- a diagnostic ultrasound platform modified to emit longer-duration, slightly higher-amplitude, focused pulses (VDAS, Verasonics Inc., Redmond, WA)
- repositioned stones in the collecting system

First-in-human clinical trial of ultrasonic propulsion of kidney stones
Jonathan D. Harper MD, Bryan W. Cunitz MS, Barbrina Dunmire MS, Franklin C. Lee MD, Mathew D. Sorensen MD MS, Ryan S. Hsi MD, Jeff Thiel, Hunter Wessells MD, James E. Lingeman MD, Michael R. Bailey PhD

- stones repositioned in 14/15 patients (43 stones)
  - 28/43 (65%) showed some movement
  - 13/43 (30%) displaced >3 mm to a new location
  - 4/6 patients passed 30 fragments after ESWL
  - largest stone moved was 10 mm
Radiation Exposure during the Evaluation and Management of Nephrolithiasis
Tony Chen, et al. Michael E. Lipkin

• 50 articles reviewed
• Evaluation and management of stones: 1.18 to 37.66 mSv
  • Those with Non-contrast CT: 14.46 mSv median
  • Conventional NCCT of the abdomen and pelvis is 10 to 20 mSv! But not at VGH
• Majority of radiation comes from CT scans
• Fluoro during PNLs increased when
  • Obese
  • Multiple tracts
  • Larger stones burden
• Ureteroscopy patients: same radiation as a KUB x-ray
• SWL: radiation not well characterized—variable

J Urol Volume 194, Issue 4, October 2015, Pages 878–

Stones and Recurrent UTIs

52 year old woman with recurrent cystitis

U/S: 5 mm right mid pole non-obstructing stone

CT-KUB: 1-2 mm right mid pole non-obstructing stone

Referral: Remove stone to reduce recurrent UTIs
Does Stone Removal Help Patients with Recurrent Urinary Tract Infections?
Mohamed Omar, Abdullahi Abdulwahab-Ahmed, Hemant Chaparala, Manoj Monga

• 120 patients with non-obstructing stones and recurrent UTIs
• How many persisted with recurrent UTIs post stone removal?
• 48% remained infection free post-op
  • 52% continued to develop recurrent UTIs
  • Particularly those with
    • Diabetes
    • Hypertension
    • Black ethnicity
• E. coli more likely to resolve
• Enterococcus did not resolve, quinolone resistant bacteria


EDGE Collaborators
- Dartmouth University
  - Vernon Pais, MD
- Duke University
  - Michael Lipkin, MD
- The Cleveland Clinic
  - Manoj Monga, MD
- Harvard Medical School
  - Brian Eisner, MD
- Johns Hopkins University
  - Brian Matlaga, MD
- Mayo Clinic
  - Amy Krambeck, MD
  - Mitchell Humphreys, MD
- NYU School of Medicine
  - Ojas Shah, MD
- Ohio State University
  - Bodo Knudsen, MD
- University of British Columbia
  - Ben Chew, MD
- University of California San Diego
  - Roger Sur, MD
- Vanderbilt University
  - Nicole Miller, MD

“When dealing with difficult diseases it is always best to have an EDGE”
Natural History, Complications, and Re-Intervention Rates of Asymptomatic Residual Stone Fragments Post-Ureteroscopy: a Report from the EDGE Research Consortium
Ben H. Chew, Hilary L. Brotherhood, Roger L. Sur, An Qi Wang, Bodo E. Knudsen, Courtney Yong, Tracy Marien, Nicole L. Miller, Amy E. Krambeck, Cameron Charchenko, Mitchell R. Humphreys

- Objectives
  - To examine the natural history, complication rates, and re-intervention rates of fragments following ureteroscopy
  - *even those >4 mm

  - To determine any patient-related or stone-related factors which may predict fragment complications

J Urol In press, Nov 2015
### Results: Pts with Fragments

% of all patients with fragments (n=232)

- No Intervention, asymptomatic: 56%
- Complication, no intervention: 15%
- Intervention: 29%

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### Results

<table>
<thead>
<tr>
<th></th>
<th>Fragment &lt;4mm</th>
<th>Fragment &gt;4mm</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passage of fragments</td>
<td>27.3%</td>
<td>26.0%</td>
<td>0.948</td>
</tr>
<tr>
<td>Growth of fragments</td>
<td>27.8%</td>
<td>59.2%*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Occurrence of Complication</td>
<td>22.3%</td>
<td>35.7%*</td>
<td>0.039</td>
</tr>
<tr>
<td>Reintervention required</td>
<td>17.5%</td>
<td>38%*</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Results

- Logistic regression shows the original stone size ($p=0.0475$) to be the only significant predictor of complication.
- There was a trend towards complication depending on the location of residual fragments ($p=0.068$) and re-intervention with older age ($p=0.075$).

Results: Size Matters!
Conclusions

• Fragments after URS >4mm have higher rates of
  • Stone growth (59.2%*)
  • Complication (35.7%*)
  • Reintervention (38%*)

• Fragments <4mm:
  - Stone growth (28%)
  - Complication rate (22%)
  - Intervene early?
    - Proximal ureter / renal pelvis fragments
    - >4 mm fragments