In Vivo Determination of Urinary Stone Composition Using Dual Energy Computerized Tomography With Advanced Post-Acquisition Processing

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Abbreviations and Acronyms

AU = ammonium urate
CAP = calcium phosphate
COD = calcium oxalate dehydrate
COM = calcium oxalate monohydrate
CT = computerized tomography
DECT = dual energy computerized tomography
MDCT = multidetector computerized tomography
SWL = shock wave lithotripsy
UA = uric acid

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Purpose: We assessed whether dual energy computerized tomography with advanced post-image processing can accurately differentiate urinary calculi composition in vivo.

Materials and Methods: A total of 25 patients scheduled to undergo ureteroscopic/percutaneous nephrolithotomy were prospectively identified. Dual energy computerized tomography was performed using 64-slice multidetector computerized tomography. Novel post-processing ($\text{DECT}_{\text{Slope}}$) used pixel by pixel analyses to generate data sets grayscale encoding ratios of relative differences in attenuation of low ($\text{DECT}_{80\,\text{kVp}}$) and high energy ($\text{DECT}_{140\,\text{kVp}}$) series. Surgical extraction and Fourier spectroscopy resulted in 82 calculi. Of these stones 51 showed minor admixtures (uric acid, ammonium urate, struvite, calcium oxalate monohydrate and brushite) and 31 were polycrystalline (mixtures of calcium oxalate monohydrate/dihydrate and calcium phosphate). Analyses identified stone clusters of equal composition and distinct attenuation descriptors on $\text{DECT}_{140\,\text{kVp}}$, $\text{DECT}_{80\,\text{kVp}}$ and $\text{DECT}_{\text{Slope}}$. Iterative cross-validation of the 3 dual energy computerized tomography data sets was used to identify characteristic attenuation limits for each stone type.

Results: Attenuation profiles showed substantial overlap among various stones on $\text{DECT}_{140\,\text{kVp}}$ (uric acid 427.3 ± 168.1 HU, ammonium urate 429.9 ± 99.7 HU, struvite 480.2 ± 123.5 HU, calcium oxalate monohydrate 852.4 ± 301.4 HU, brushite 863.7 ± 180.1 HU and polycrystalline 858.1 ± 210.5 HU) and on $\text{DECT}_{80\,\text{kVp}}$ (uric acid 493.6 ± 182.8 HU, ammonium urate 591.5 ± 157.9 HU, struvite 712.4 ± 173.9 HU, calcium oxalate monohydrate 1,240.5 ± 494.7 HU, brushite 1,532.1 ± 273.1 HU and polycrystalline 1,358.7 ± 316.8 HU). Statistically spectral separation was not sufficient to characterize stones unambiguously based on $\text{DECT}_{140\,\text{kVp}}/\text{DECT}_{80\,\text{kVp}}$ attenuation. Analysis of attenuation showed sufficient spectral separation on $\text{DECT}_{\text{Slope}}$ (uric acid 14.9 ± 10.9 U, ammonium urate 56.1 ± 1.8 U, struvite 42.7 ± 1.4 U, calcium oxalate monohydrate 62.8 ± 1.8 U and brushite 113.2 ± 5.3 U). Polycrystalline stones (51.8 ± 3.7 U) overlapped with struvite and ammonium urate stones. This overlap was resolved as all struvite/ammonium urate stones measured 900 HU or less and all polycrystalline stones measured more than 900 HU on $\text{DECT}_{80\,\text{kVp}}$.

Conclusions: Dual energy computerized tomography with novel post-processing allows accurate discrimination among main subtypes of urinary calculi in vivo and, thus, may have implications in determining the optimum clinical treatment of urinary calculi from a noninvasive, preoperative radiological assessment.

Key Words: tomography, x-ray computed; urolithiasis; calculi

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DETERMINING urinary stone composition using solely radiological tools has been an elusive task during the last 10 years. Ideally this ability will render the invasive, time-consuming and expensive operative extraction of urinary calculi for the sole purpose of chemical analysis unnecessary, and under certain circumstances may enable an almost immediate initiation of medical management for the prevention of stone formation. Furthermore, knowing the stone composition will permit the urologist to individualize operative management decisions based on the most appropriate interventional treatment for stone fragmentation.

In a recent in vitro study DECT was combined with advanced pixel by pixel post-processing algorithms for substantially improved characterization of renal stone composition in vitro.[1] This study was designed to test the hypothesis that DECT with advanced post-processing can accurately differentiate various stone compositions in vivo and, thus, may serve as an important tool when tailoring treatments for patients with stones of all compositions.

MATERIALS AND METHODS

This prospective study was Health Insurance Portability and Accountability Act compliant, and institutional review board approved.

Patient Recruitment

From June 2008 to July 2009 a total of 25 patients referred to the Comprehensive Kidney Stone Center at our tertiary care medical center for removal of symptomatic renal calculi were included in this study. All patients received a noncontrast enhanced dual energy MDCT evaluation within 5 days before undergoing elective endoscopic surgery. The entire study population of 25 patients included 11 women 28 to 68 years old (mean age 60.8 ± 13.5) and 14 men 26 to 78 years old (mean age 51.3 ± 11.4).

Dual Energy MDCT Acquisition

All dual energy MDCT data acquisition was performed using a 64-slice MDCT system with a dual source/dual detector design, that is 2 x-ray tubes and detector arrays arranged in perpendicular configuration for simultaneous dual energy MDCT imaging (SOMATOM® Definition). The helical scanning parameters used in this study correspond with the vendor suggested clinical and dose optimized nephroureteral noncontrast enhanced dual energy MDCT protocol, that is a 1.5 mm nominal section thickness with a 1 mm reconstruction increment, a pitch of 0.55, a gantry rotation period of 0.5 seconds, a collimation of 1.2 mm, a matrix size of 512 × 512 pixels within a 250 mm field of view, for simultaneously acquired high energy data sets at 140 kVp and 118 mAs per rotation, and low energy data sets acquired at 80 kVp and 499 mAs per rotation.

The institutional review board required a prestudy radiation dose assessment comparing single vs dual energy radiation profiles. Metal oxide field effect semiconductor transistors placed in an anthropomorphic dose phantom confirmed comparable dose profiles between the single energy (120 kVp) imaging sequence (estimated radiation dose 8.52 mSv) and the dual energy (80 and 140 kVp) imaging sequence (estimated radiation dose 9.56 mSv).

Surgical Renal Stone Extraction and Fourier Infrared Spectroscopy

In the study population of 25 patients 82 individual stones were identified by DECT, averaging 5.6 ± 3.2 mm in cross-sectional diameter and ranging from 2.1 to 11.9 mm. There were 18 patients who underwent percutaneous nephrolithotomy and 7 who were treated with ureteroscopic stone removal. After surgical extraction of renal calculi the stone composition was assessed with Fourier infrared spectroscopy to precisely differentiate all crystalline components (StoneComp, Mission Pharmacal, San Antonio, Texas).

A composition of 70% or greater of a single crystalline component was considered minor admixture. The analyzed 51 minor admixture stones consisted of 16 uric acid ($C_5H_4N_4O_3$), 7 ammonium urate (NH4-urate), 5 struvite ($H_{18}MgNO_{10}P$), 14 calcium oxalate monohydrate ($CaC_2H_2O_4 \bullet 1H_2O$) and 9 brushite ($CaHPO_4$). All analyzed 31 major admixture polycrystalline calculi were composed of various concentrations of calcium oxalate (as $CaC_2H_2O_4 \bullet 1H_2O$ or as $CaC_2H_2O_4 \bullet 2H_2O$) and calcium phosphate ($Ca_3(PO_4)_2$).

Spectral Based Renal Stone Characterization

Image data post-processing in our in vivo trial analyzed renal calculi composition by assessing the ratio of relative differences in attenuation values of various renal stones in the low energy and high energy DECT data sets.[1] By using this previously proposed in vitro approach in an in vivo patient population, entirely new image series ($DECT_{Slope}$) were created outside the conventions of the CT Hounsfield attenuation system. The $DECT_{Slope}$ series color encoded ratio variations of originally acquired lower energy ($DECT_{80\,kVp}$) and higher energy ($DECT_{140\,kVp}$) image series, using a pixel by pixel approach with commercially available software applications (syngo® MultiModality Workplace, Version VE25A).

Renal stone assessment was facilitated by selecting 1 central transverse imaging plane through the largest cross-sectional profile for each stone on the high energy ($DECT_{140\,kVp}$) image series. Subsequently freehand regions of interest were placed along the inner contours of the renal stone margins. Finally, size and location of these regions of interest were automatically mirrored to the corresponding imaging planes of the low energy ($DECT_{80\,kVp}$) and post-processed ($DECT_{Slope}$) image series. Manual parameter sampling was performed by 1 radiologist (DTB) with more than 10 years of experience in CT data post-processing. All measurements were repeated 3 times with an interval of more than 1 week between each of the 3 measurement repetitions, and the measurement results were subsequently averaged.

Graphical data analysis was performed by plotting Hounsfield attenuation values attained from the originally acquired high energy ($DECT_{140\,kVp}$) and low energy ($DECT_{80\,kVp}$) image series for each stone type, graphically outlining mean attenuation, lower and upper quartile