Published in final edited form as:

Urology. 2014 September ; 84(3): 561–564. doi:10.1016/j.urology.2014.05.010.

Accuracy and efficiency of determining urinary calculi composition utilizing Dual-Energy Computed Tomography (DECT) compared to Hounsfield Unit (HU) measurements for practicing physicians

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Abstract

Objectives—To compare speed and accuracy for determining urinary calculi composition between dual-energy computed tomography (DECT) and Hounsfield Unit (HU) measurements of calculi by a set of reviewers at varying levels of training and practice.

Methods—Sixteen patients with known stone composition were randomly selected. Fourteen reviewers of varying levels of practice interpreted DECT and HU images from the selected patients to predict stone composition in two sessions (day 1: tutorial/flow sheet available for image interpretation; day 2: tutorial/flow sheet not available). Reviewers recorded HU values, stone color, and predicted stone composition as they were timed. Accuracy of image interpretation, determination of calculi composition, and interpretation time were compared.

Results—DECT accuracy: Image interpretation 100% (day 1) and 94% (day 2); predicted stone composition 100% (day 1) and 73% (day 2). Mean interpretation time was the same for both days, 21 sec/study (range 11–40 sec). HU accuracy: Image interpretation 97% (day 1) and 91% (day 2); predicted stone composition was 45% accurate on both days. Mean interpretation time was 53 sec/study (range 28–79 sec) and 41 sec/study (range 19–71 sec) on days 1 and 2, respectively. Overall accuracy of determination of stone composition and interpretation time for DECT were essentially double that of the HU images (87% vs. 45% and 21 sec vs. 47 sec, respectively). Reviewer's experience level did not affect accuracy or speed

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Conflict of Interest: MAJ: None; EHI: None; AT: None; JGC: None; WEH: None; DDT: None.

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Conclusion—DECT is easier to learn, faster to interpret, and more accurate than HU in determining urinary calculi composition for physicians at various levels of training and practice.

Keywords

dual-energy computed tomography (DECT); urolithiasis; Hounsfield Unit; stone composition

Introduction

There is a growing number of imaging modalities, imaging protocols, and laboratory values with which physicians and trainees must be familiar in order to diagnose and treat urinary stone disease. These physicians must be able to interpret the images with accurate results in order to provide appropriate care. Increasing the simplicity of interpretation will likely decrease the amount of time required to learn how to read an exam. Computed tomography (CT) is commonly used to diagnose urolithiasis due to its high sensitivity and specificity.¹⁻⁴ Conventionally, Hounsfield Unit (HU) measurements of calculi imaged with single-energy CT (SECT) have been used to predict stone composition and guide stone treatment. However, HU evaluation of stones imaged by SECT is cumbersome with variable reported accuracy.⁵⁻⁸

Recently, dual-energy CT (DECT) has been introduced for imaging patients with urinary calculi. With DECT, the patients are imaged at two different x-ray energies (typically, 140 kV and 80 kV), and the change in attenuation is used to determine stone composition.⁹⁻¹⁴ DECT is nearly 100% accurate in differentiating uric acid (UA) from non-UA composition for calculi 3 mm or greater.⁹⁻¹⁴ Therefore, DECT has the potential to improve patient management decisions since UA calculi can be treated medically, whereas non-UA calculi typically require an invasive treatment.^{15,16} DECT exam time, scan cost, radiation exposure, and anatomic details are similar to those seen with SECT.¹⁷ This study aims to compare the accuracy and speed of image interpretation between DECT material-specific images and conventional diagnostic images utilizing HU measurements for determination of urinary calculi composition in a set of physician reviewers at varying levels of training and practice.

Materials and Methods

Sixteen imaging exams were randomly selected for interpretation from a database of 60 patients in which DECT material-specific images, diagnostic HU images, and recovered stone material were available. Of the randomly selected calculi, 15 were non uric-acid (UA) and 1 was UA (6%), reflective of the population prevalence of 5–8% UA calculi. Also, one patient had a ureteral stent in place adjacent to the stone of interest, reflective of the stent prevalence in our imaged population (5%). A single axial image displaying the stone of interest for each exam was loaded into a DICOM viewer (RadiAnt DICOM Viewer; version 1.1.8) for interpretation.

Fourteen physicians (six postgraduate year [PGY] 1 interns, four urology residents [PGY 2 – PGY 4], and four urology attending surgeons) reviewed DECT material specific images and diagnostic HU images from the selected patients. The reviewers were evaluated on two separate days. On the first day, each reviewer was given a tutorial on how to use the DICOM

viewing software (Supplemental Figure). The reviewers were also given a flow chart for interpretation of both DECT material-specific images and diagnostic/HU images. After the tutorial, each reviewer was shown 16 single images (eight diagnostic [HU] and eight DECT material-specific, in alternating order) displaying the stone of interest for each patient. They were asked to answer the following questions for each exam: 1) How many stones are present? 2) In which kidney are stones present? (right, left, both, or none) 3) Color/HU of the stone? 4) What is the stone's composition? (UA, Non-UA, mixed, or not characterized). The reviewers were timed per study.

Each reviewer returned for a second day with varying amounts of time between the first and second session (mean: 6.3 days, range: 1–32 days). On the second day, no flow chart was provided. Each reviewer was again shown the same 16 cases; the eight originally presented as DECT material-specific were presented as diagnostic HU films and vice versa. The same set of questions was asked for each exam. Reviewers were again timed per study. A questionnaire was given to each reviewer at the end of day two regarding their confidence level (from 1–5; 5 being the most confident) with interpretation of DECT material-specific images and diagnostic/HU images and which imaging modality they preferred.

Since the reviewers were only given a single image for interpretation, they were asked to point to each stone as they recorded their findings. If the reviewer did not correctly identify the stone of interest for a certain patient, this patient was not included in their accuracy measurements for that modality. This situation was only encountered in two patients. One patient had altered anatomy, with the stones contained in an Indiana pouch, which made interpretation difficult for PGY-1 reviewers who were unfamiliar with the anatomy. As a result, this stone was not included in the accuracy measurements for five of the six PGY 1 reviewers, but was included for all PGY 2 and above reviewers. The other patient had a ureteral stent in place adjacent to the stone of interest. Again, since only a single image was available, some reviewers (four PGY 1, one PGY 2, and two attendings) mistook the stent for a stone on either the DECT material-specific or diagnostic images; therefore, this patient was not included in their accuracy measurements.

Results

Table 1 summarizes the accuracy of image interpretation, predicted stone composition, and time per study for DECT material-specific images. Overall, the reviewers were correctly able to interpret DECT material-specific images with an overall accuracy of 97%, but dual-energy analysis was only correct in identifying stone composition with 87% accuracy. The difference in accuracy between day 1 and day 2 was statistically significant ($p<0.01$).

Table 2 summarizes the accuracy of image interpretation, predicted stone composition, and time per study for diagnostic HU imaging. Reviewer accuracy of diagnostic HU image interpretation was not statistically different from day 1 to day 2 (97% vs 91% $p=0.4$). The difference in accuracy between days 1 and day 2 was not statistically significant ($p=0.88$). The difference in accuracy of predicted stone composition between DECT images and HU measurements was statistically significant for day 1 (100% vs. 45%, $p<0.001$), day 2 (73% vs. 45%, $p<0.001$), and overall (87% vs. 45%, $p<0.001$).

The average interpretation time for the diagnostic/HU images was statistically improved from day 1 to day 2 (53 seconds versus 41 seconds, $p<0.001$). Mean DECT material-specific image interpretation time (21 seconds per study) was the same for day 1 and day 2. This was 60% faster than interpretation of the diagnostic/HU images on day 1 and 45% faster than interpretation of the diagnostic/HU images on day 2. Overall, the interpretation of the DECT material-specific images was on average 55% faster than HU image interpretation.

Questionnaire data showed reviewer mean confidence of interpretation of 2.6 for the diagnostic/HU images and 4.1 for the DECT material-specific images. Thirteen of the fourteen reviewers listed DECT as their preferred imaging modality compared to standard HU imaging.

Discussion

HU evaluation of stone composition is limited by overlapping values between stone types, variation in interoperator region-of-interest (ROI) selection, and equipment (type of CT scanner, slice thickness, and scan energy).⁵⁻⁸ Also, mixed stones present a challenge for traditional HU measurements; HU may be high, midrange, or low, depending on the percentage mixture and where the operator chooses to draw the ROI.⁵⁻⁸ Patients treated with ureteral stents present a further drawback to using HU for predicting stone composition, as the stent material can be included in the ROI and results in measurement error. Thus, HU evaluation of stones imaged by SECT is cumbersome with variable reported accuracy.^{5-8,18}

DECT uses the change in attenuation between two different scan energies to determine stone composition with nearly 100% accuracy in differentiating UA from non-UA composition for calculi 3 mm or greater.⁹⁻¹⁴ Basic image interpretation of DECT material-specific images is simple; calculi composition is displayed according to color: UA calculi are displayed in one color (eg, red) and non-UA calculi are displayed in another (eg, blue). A more detailed discussion of image interpretation has been previously described in the literature.¹⁹ Further, DECT exam time, scan cost, radiation exposure, and anatomic details are similar to those seen with SECT. Therefore, DECT has the potential to improve patient management decisions compared to SECT. The overall accuracy of predicted stone composition and speed of interpretation for DECT material-specific images was essentially double those of the diagnostic HU images. A strong interobserver agreement of stone composition was seen for both the DECT material-specific and diagnostic/HU images with universal agreement of the predicted stone type on 15 of the 16 calculi based on DECT material-specific images, and nearly universal agreement of the predicted stone type on 13 of the 16 calculi based on HU measurements.

The average HU measurements of the eight nearly universally incorrectly interpreted non-UA stones were well within the UA range used in this study (540 or less), with two standard deviations above the mean still within the range of UA. This suggests that the reviewers were able to accurately draw and interpret the ROI according to the provided criteria, but the HU measurements were not accurate in characterizing the stone.

The dual-energy algorithm did not accurately predict stone composition for two calculi on the second day. The first was a 2 mm stone in the distal ureter composed of 95% calcium phosphate (apatite) and 5% calcium oxalate dihydrate not characterized by the dual-energy algorithm; this is less than the known 3mm limitation of dual-energy analysis and is likely small enough in size not to be clinically relevant. The other was a 5mm mixed-composition calculus (70% calcium oxalate monohydrate, 20% uric acid, and 10% calcium oxalate dihydrate) in the distal ureter characterized by dual-energy analysis as blue/non-UA. All reviewers correctly interpreted the dual-energy analysis of this stone as blue (non-UA); however, the actual stone composition was mixed, and thus it was not correctly determined by reviewers. Given that the stone was predominately non-UA in composition, one could argue that dual-energy analysis was not entirely incorrect in characterizing this stone, given that clinical management will be based on the predominantly non-UA component.

Another possible confounding variable to HU interpretation was the mechanism of image acquisition. The diagnostic images used in this study were acquired using a dual-source DECT scanner (Somatom definition flash, Siemens) operated in the dual-energy mode rather than conventional SECT scanner. In this imaging modality, linearly mixed low- and high-energy data sets are used to compute attenuation values (measured in HU) and create virtual 120 kV diagnostic images.¹⁷ Prior studies have shown these images to have a similar image quality and contrast-to-noise ratio as conventional SECT.¹⁷ However, weighted averages are used to create these images, and it is possible that they may not completely reflect the HU seen on conventional SECT and, thus, may have contributed to the decreased accuracy of diagnostic HU image interpretation.

DECT imaging is increasing in prevalence, with many potential applications other than the analysis of stone composition. Specific to urology, DECT has been proposed as a way of scanning multiphase CT excretory urography (CT EXU) and using iodine subtraction to create virtual non-contrast (VNC) images for stone evaluation.²⁰ Current software parameters do not allow for both iodine subtraction and stone composition analysis. Thus, if a patient is scanned in the dual-energy mode but the material-specific algorithm for determining the stone composition (which creates the material-specific images used in this study) is not performed, it is still possible for a physician to use HU measurements on these images to determine the stone composition. Therefore, based on our small sample, we suggest conducting further evaluation of the HU measurements of calculi on dual-energy diagnostic images to compare the accuracy of reported stone composition with conventional SECT.

The interpretation times for the diagnostic/HU images were significantly longer than the DECT material-specific images. The interpretation time improvement for diagnostic/HU image interpretation from day one to day two indicates a learning curve. However, the interpretation times of the diagnostic/HU images remained significantly longer than the DECT material-specific images, and accuracy of the diagnostic image interpretation did not improve despite the increased speed. Conversely, the interpretation times for the DECT material-specific images were very fast and very accurate from day one, leaving little room for improvement between day one and day two. Therefore, this study suggests that the

DECT material-specific images are faster to interpret, easier to learn, and are more accurate than diagnostic/HU images.

The level of the reviewer's experience (PGY 1 through attending) did not affect the accuracy for image interpretation of the DECT material-specific or diagnostic/HU images; although, the DECT material-specific images were generally more accurate, faster to interpret, and had less of a learning curve. Thus, the material-specific DECT images are useful for both experienced and inexperienced interpreters. The questionnaire data from the reviewers also suggests that they felt more confident interpreting the DECT images and preferred this imaging modality over conventional HU interpretation.

Conclusion

DECT is easier to learn, faster to interpret, and more accurate than traditional HU interpretation of urinary calculi with regard to determining stone composition across a wide range of physician levels and experience

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Support/Financial Disclosure: This project was supported by a grant from the National Institutes of Health (Mayo Clinic Urology Research Center grant DK 83007) and the Mayo Clinic.

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Table 1

Summary of Dual-Energy Computed Tomography (DECT) Material-Specific Image Evaluation

DECT Material Specific Images				
	Average Reviewer Accuracy of Image Interpretation	Accuracy of Dual-Energy Analysis	Reviewer Accuracy of Predicting Stone Composition	Average Time/Study, in seconds (range)
Day 1	100%	100%	100%	21 (11–40)
Day 2	94%	73%	73%	21 (14–36)
Overall	97%	87%	87%	21

Table 2

Summary of Diagnostic/Hounsfield Unit (HU) Image Evaluation

Diagnostic/HU Images				
	Average Reviewer Accuracy of Image Interpretation	Accuracy of HU values	Reviewer Accuracy of Predicting Stone Composition	Average Time/Study, in seconds (range)
Day 1	97%	45%	45%	53 (28–79)
Day 2	91%	45%	45%	41 (19–71)
Overall	94%	45%	45%	47