Endourology and Stones

Dual-energy vs Conventional Computed Tomography in Determining Stone Composition

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OBJECTIVE To compare the accuracy between conventional computed tomography (CT) and dual-energy CT (DECT) in predicting stone composition in a blinded, prospective fashion.

METHODS A total of 32 renal stones with known composition were scanned in vitro, first using standard CT techniques at 120 kilovolt peak (kV[p]) and then using fast-switched kilovolt DECT at 80 and 140 kilovolt peak (kV[p]). For the DECT scan, a spectral curve was created demonstrating the change of Hounsfield units (HU) across the kiloelectron volt spectrum. The composition of each stone was estimated by comparing each sample curve with curves of known materials. To attempt stone determination using single-energy CT, the HU of each stone was compared with ranges reported in previous studies. The accuracy of each method was compared.

RESULTS Included were 27 stones large enough to allow analysis. Single-energy measurements accurately identified 14 of 27 stones of all composition (52%), whereas the DECT spectral curves correctly identified 20 (74%). When analyzed by stone type, single-energy vs DECT correctly identified 12 vs 12 of the 12 uric acid stones, 2 vs 3 of the 6 struvite stones, 0 vs 3 of the 5 cystine stones, and 0 vs 2 of the 4 calcium oxalate stones, respectively. When simply attempting to differentiate uric acid vs nonuric acid stones, single-energy CT could accurately differentiate only 6 of 15 stones as nonuric acid (40%) compared with 14 of 15 stones (93%) for DECT.

CONCLUSION DECT appears to be superior to conventional CT in differentiating stone composition and is particularly accurate in differentiating nonuric acid from uric acid stones. UROLOGY ■: ■–■, 2014. © 2014 Elsevier Inc.

The evaluation and treatment of urolithiasis represents a heavy and increasing burden on the United States health care system. The lifetime risk of stone formation exceeds 12% in men and 6% in women and has increased during the last quarter of the 20th century.[1] The estimated annual cost to the United States health care system was $2.1 billion in 2000, not accounting for lost work and productivity.[2]

Imaging plays a vital role in the accurate diagnosis of urinary stones. Plain radiography and intravenous urography were traditionally the imaging modalities of choice; however, the noncontrast computed tomography (CT) scan has now become the gold standard for evaluating patients with symptoms suggestive of urolithiasis. CT has excellent sensitivity and specificity for detecting the presence of stones and is reliable in determining their size and location, which in turn assists in directing treatment.

The successful treatment of urolithiasis largely depends on stone composition. For example, that uric acid stones may be managed medically and that certain stone types are resistant to shockwave lithotripsy (SWL) is well established. Ideally, stone composition could be determined at the time of the initial imaging, thereby directing treatment before subjecting the patient to a procedure that may be unnecessary or unsuccessful. This is a major limitation of conventional CT scanning.

Dual-energy CT (DECT) is a promising new technology that has the potential to improve our current ability to differentiate stone phenotypes by composition. The limitation of conventional "single-energy" scanning is that the Hounsfield unit (HU) value of any object is related to its attenuation coefficient, which depends not only on its composition and density but also on the energy of the photons interacting with it. Therefore, an object's attenuation coefficient is not unique at a single energy level and can be indistinguishable from other materials. DECT involves scanning at 2 different energy levels, typically 140 and 80 kilovolt peak (kV[p]), thus obtaining a different (typically at a lower energy) attenuation coefficient to help discriminate different material compositions.

Three different general configurations are currently used commercially for DECT, each applying a different technique. The Siemens Medical Solutions SOMATOM Definition scanner was the first DECT scanner available.

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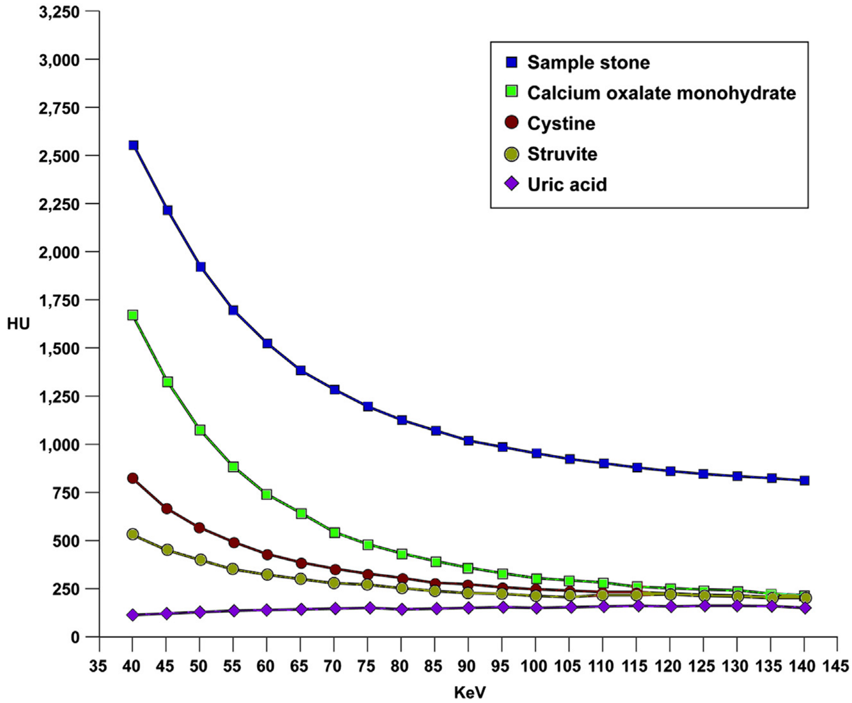

Figure 1. The spectral curve generated from a sample stone compared with spectral curves provided by National Institute of Standards and Technology. The slope of the sample curve very closely approximates the curve for known calcium oxalate monohydrate. HU, Hounsfield unit. (Color version available online.)

This uses a dual-source technique, with 2 x-ray tubes arranged with an angular offset of 90°-95°. These work simultaneously at the 2 desired energy levels. The second method, as used by the GE Healthcare Discovery 750 HD, uses 1 x-ray tube that rapidly switches between 80 and 140 kV(p). This is referred to as "fast kV-switching", and has a time interval of 0.4 milliseconds. The third configuration, seen in the Philips Healthcare Brilliance 64, involves a single source but a dual-layer multidetector. This detector has 2 "sandwich" layers: the first layer absorbs most of the low-energy spectrum, and the second absorbs the higher-energy spectrum. The images are then reconstructed separately from the 2 layers, alleviating the need to have 2 separate beams.

Previous studies have shown DECT is accurate in determining multiple phenotypes in both in vivo and ex vivo studies.[3-6] A direct comparison of DECT with conventional CT in a retrospective fashion found DECT had much less overlap in attenuation values between 7 different stone types.[7] However, no study to date has used a blinded clinician and preset reference ranges to determine how DECT accuracy compares prospectively. In this study, we aim to compare the accuracy between DECT and conventional CT in determining stone phenotype.

MATERIALS AND METHODS

Thirty-two renal stones with a known, pure composition, as determined by infrared spectroscopy, were placed in a water bath measuring 25 cm high × 40 cm wide to simulate the scatter from a normal body habitus. Stone size ranged from 1-10 mm and consisted of pure uric acid, cystine, struvite, and calcium oxalate monohydrate.

The stones were scanned using conventional imaging techniques at 120 kV(p) and subsequently using fast kV-switching DECT, using the same scanner (GE Healthcare Discovery 750 HD). The scanning protocol used 40-mm beam collimation, with 0.625-mm slice data acquisition, 0.984:1 pitch, and large bowtie filter matching our routine abdominal scanning technique.

For the DECT analysis, overlapping monochromatic images were reconstructed at 1.25-mm slice thickness and 0.625-mm increments. These images were viewed on a processing workstation capable of displaying pixel values for monochromatic images from 40-140 keV. A blinded clinician drew a small circular region of interest (ROI) within each stone. A plot demonstrating the change of monochromatic HUs across this kiloelectron volt spectrum was created for the ROI for each sample stone, and each sample curve was compared with the curves of known materials obtained from the National Institute of Standards and Technology (NIST). Figure 1 demonstrates a plot of a spectral curve generated from a sample stone compared with the NIST curves. To determine the stone subtype using DECT, the following formula was applied to the ROI:

$$\text{HU value at 40 keV} - \text{HU value at 140 keV}$$

This formula was also applied to the NIST curves for the known materials. A reference range was then generated so that the upper and lower limits of each reference stone phenotype went halfway to the next phenotype's value to avoid any overlap in the ranges. The value obtained for the ROI on our sample stones was compared with the NIST reference range to classify each stone into 1 of the 4 subtypes.