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Multi-Energy Computed Tomography - New Opportunities In Imaging the Abdomen

- **Materials can be distinguished based on their differences in attenuation properties at different x-ray energies. Attenuation of x-rays due to high atomic weight substances such as calcium and iodine is greater at lower energy settings (80 kVp) than at higher settings (140 kVp)**
- **CT scanners are now available that can almost simultaneously acquire images at two energy levels, either by using two x-ray tubes or a single x-ray tube capable of rapid energy (kVp) switching**
- **Multi-energy scanning may be advantageous in the abdomen for several purposes, including: determining the composition of urinary stones, detection and characterization of abdominal lesions, generating virtual unenhanced images from the enhanced data sets, and improving the performance of CT angiography, CT venography, and CT colonography**
- **The advantages of improved lesion detection and characterization must be weighed against the potential for increased radiation exposure. However, improved lesion characterization may lead to fewer future scans, and the ability to eliminate a non contrast scan in multiphase CT studies with a virtual non contrast scan can decrease overall radiation doses for many studies**

In conventional x-ray imaging, including CT, the peak tube voltage (kVp) is a variable setting that affects image contrast, especially that due to differences in attenuation of high molecular weight substances such as iodine and calcium. For example, attenuation due to iodine at 80 kVp is approximately double that at 120-140 kVp. However, if the tube current (mA) is not adjusted appropriately to compensate for lower kVP, high noise levels can degrade CT image quality. This problem is more prevalent on old scanners with relatively low x-ray tube output and when there is increased attenuation by patients of larger body habitus. For this reason, CT has typically been performed at 120-140 kVp in order to obtain images of expected quality to enable physicians to confidently render appropriate diagnoses.

It should be noted that imaging at any selected kVp is, in fact, spectral imaging over a range of energy levels, with a peak energy level approximately half of the nominal kVp. Although these images are relatively simple to acquire, their processing and interpretation has limitations inherent to polychromatic beam spectra in characterizing various materials and tissues.

The alternative, multi-energy scanning, employs two or more monochromatic (keV) beams, which have less variability in energy level and mean energies that are closer to the peak energies. The basic concept of multi-energy scanning is to characterize and quantify the molecular composition of certain tissues and added contrast agents based on predictable differences in attenuation when substances are imaged with different x-ray energies of known spectra. By applying a base material decomposition algorithm, multi-energy data can be processed to enable material composition analysis or to make certain attributes of the tissues more conspicuous. Indeed, this principal is exploited in dual-energy x-ray absorptiometry (DEXA) bone density studies.

Until recently, multi-energy CT imaging was not of practical value for evaluating most tissues because the speed of image acquisition was not sufficient and, if consecutive images were acquired, motion artifacts would result in misregistration.

Recently, manufacturers of CT scanners have produced new machines that offer multi-energy scanning by using concurrent monochromatic x-ray beams of two different energies. In one design, this is achieved by mounting two x-ray tubes in the gantry, which are set at different energy levels. In another design, multi-energy scanning is achieved by rapid switching between energy levels. Mass General Imaging has one of each of these kinds of scanners installed on the main campus.

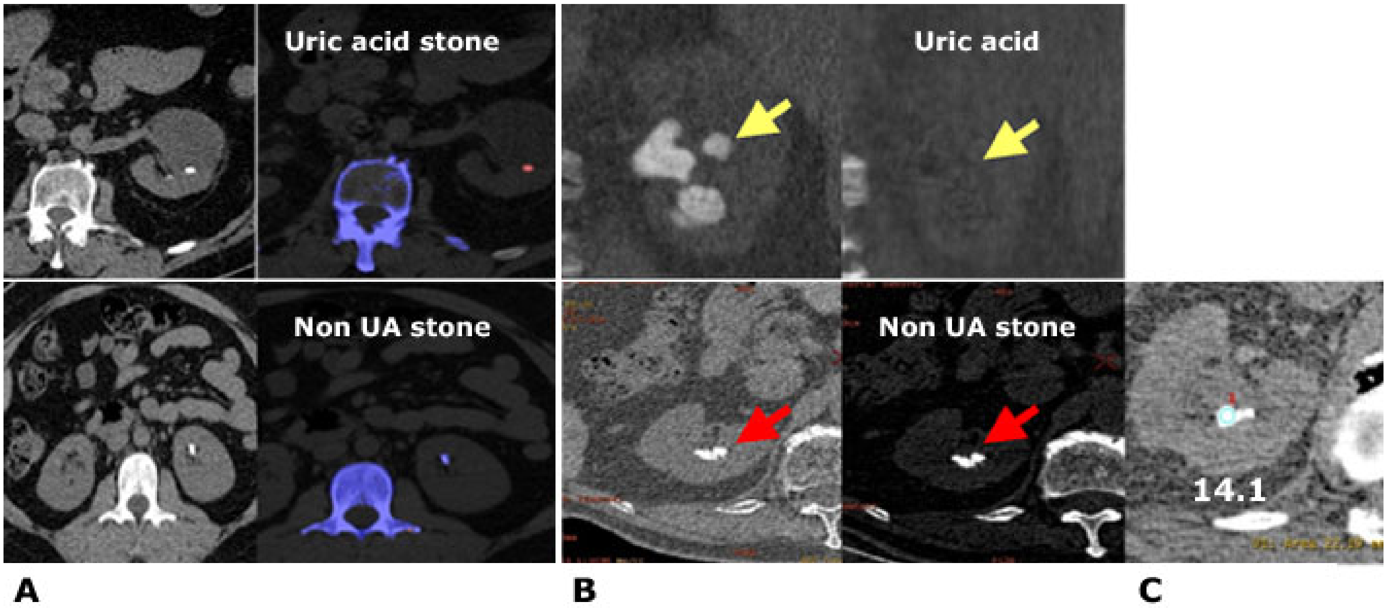

Figure 1. Renal stone characterization A) Color coded images from dual source /dual energy CT showing uric acid (UA) stone encoded in red and non-UA stone encoded in blue. **B**) In single source dual energy CT material density (MD) images (from two different patients), pure UA stones (yellow arrow) are apparent only on MD water, where as non-UA stones (red arrow) are seen on both MD water as well as MD iodine images. **C)** The non-UA stone on effective Z image had an effective Z (atomic number) of 14.41 and later, on spectroscopic stone analysis, was shown to be composed of 100% calcium oxalate.

Visualization of Multi-Energy Images

Side-by-side comparisons of images obtained at 80 kVp and 140 kVp show obvious differences in attenuation due to calcium and, in contrast-enhanced images, iodine. However, post processing of CT data can provide more useful images. Post-processing algorithms can blend the two images to take advantage of the increased attenuation of iodine and/or calcium at lower kVp while retaining the high image quality of the higher kVp. These blended images can aid in lesion detection.

Alternatively, base material decomposition algorithms quantify the materials that make up an imaged object to, for example, highlight iodine uptake, in which case iodine color maps are created as an overlay of the anatomic images. In addition, it is possible to remove data attributable to iodine to create virtual non-contrast images. Similarly, images can be created that either highlight or eliminate calcium.

The detectors in some scanners are able to differentiate the different energy levels, which allows the creation of virtual monochromatic data sets. These scanners can simulate a situation in which images are generated from a single energy (keV) beam ranging from 40-140, thereby providing more flexibility than is possible with standard CT. Multi-energy CT can also reduce the image degrading beam-hardening artifacts, particularly in the vicinity of dense bone, metallic prostheses or surgical clips.

Renal Stones

Renal stone characterization is one of the most well established uses of multi-energy CT applications (see Radiology Rounds, July 2008). All types of renal stones appear hyperdense on single-energy CT, and the small differences in attenuation between uric acid (UA) and non-UA stones are often not sufficient for their characterization. Characterization between UA and non UA stones can guide appropriate treatment. In contrast, characterization of stones into UA and non-UA types by multi-energy CT techniques is feasible with more than 90% sensitivity and specificity in the diagnosis. Substratification of non-UA stone types is also possible by estimating their mean atomic number, a signature of underlying chemical composition (Figure 1).

Lesion Detection and Characterization

The underlying principle in using CT for lesion detection and characterization is based on differences in contrast and tissue perfusion/enhancement between the pathology and its background. However, beam-hardening artifacts from polychromatic x-ray beam and partial volume averaging with the background tissue often makes lesion detection and characterization difficult.

In multi-energy CT, the generated iodine maps can highlight the distribution of iodine within a given volume of tissue. Because these maps are sensitive enough to detect subtle contrast enhancement, they enable reliable diagnosis of an enhancing mass or non-enhancing cyst (Figure 2). The iodine maps or low energy (kev) monochromatic images can also improve the detection of subtle abnormality or assess tissue viability. This has benefits in patients evaluated for Crohn's disease and bowel ischemia.

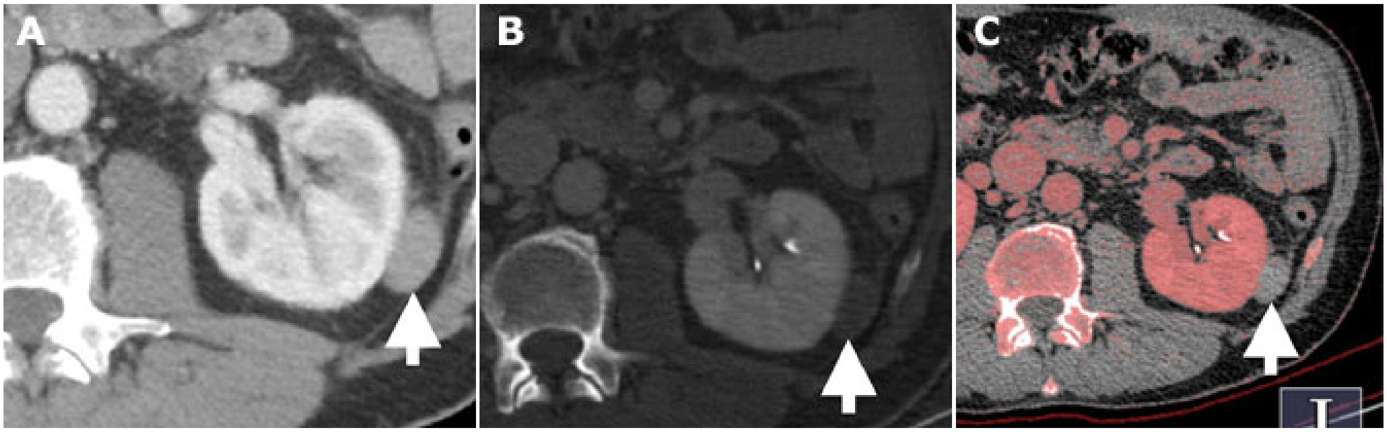

Figure 2. Renal Lesion Characterization. Contrast enhanced image from single energy CT **(A)** showing exophytic cyst (arrow) with hyperdensity which is suspicious for malignancy or could be secondary to hyperdense cyst. Iodine image **(B)** and color over lay map **(C)** derived from multi-energy CT acquisition shows that the lesion does not enhance (arrow) inferring it to be a hyperdense cyst.

Multi-energy CT also has potential for monitoring response to therapy for cancer. Tumors that respond to therapy have reduced blood flow and blood vessel permeability. CT perfusion studies can demonstrate these changes, but they cover a limited body region, require expertise and a sophisticated protocol of multiple image acquisitions as contrast material enters and then leaves the tissues. CT perfusion studies also carry a penalty of higher radiation burden. Similar information can be derived from a multi-energy CT image because iodine uptake in tumors is directly related to blood flow and permeability. In addition, multi-energy CT is better for identifying necrotic tissue because it is not perfused and does not take up contrast material.

Virtual Unenhanced Images

Many studies have already validated the performance and attenuation properties of various tissues of virtual non-contrast images for organs like the liver, kidneys and pancreas (Figure 3). This type of image serves a dual objective of simplifying multiphase CT protocols and lowering radiation dose by eliminating the unenhanced CT scan.

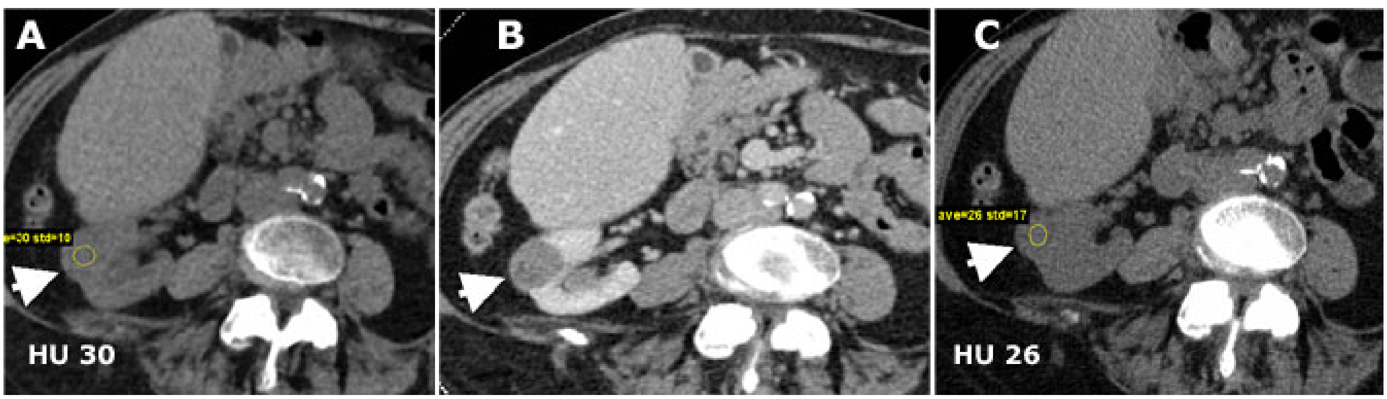

Figure 3. Renal Lesion Characterization. Virtual unenhanced image **(A)** derived from contrast enhanced multi-energy CT acquisition **(B)** shows a right renal lesion (arrow) with similar performance in detection and Hounsfield units as true unenhanced CT **(C)**.

CT Angiography

CT angiography (CTA) has become widely used for the assessment of vascular disease throughout the body. CTA performed with multi-energy CT has several potential advantages over single energy CTA. First, because the detection of iodine is more sensitive, it should be possible to lower the dose of contrast material by preferentially using low kV/low energy monochromatic images from multi-energy CT. This may be beneficial for patients with fragile kidneys and poor kidney function or for those who may be more susceptible to adverse reactions to contrast materials. Second, multi-energy CT may improve the ability to efficiently visualize the lumen of blood vessels in patients with calcified atherosclerotic plaque by using post-processing methods to remove the CT data attributable to calcium and providing a true estimate of vessel narrowing. Calcium stripping and bone subtraction is also more accurate, thereby providing three-dimensional images of the true vascular lumen.

CTA is also used for routine monitoring after endovascular repair of abdominal aortic aneurysms (EVAR). The most common complication after such repair is an endoleak, in which perfusion of the aneurysm recurs. The standard CT protocol for endoleak detection is a triple-phase scan, with an unenhanced phase, an arterial phase, and a contrast-

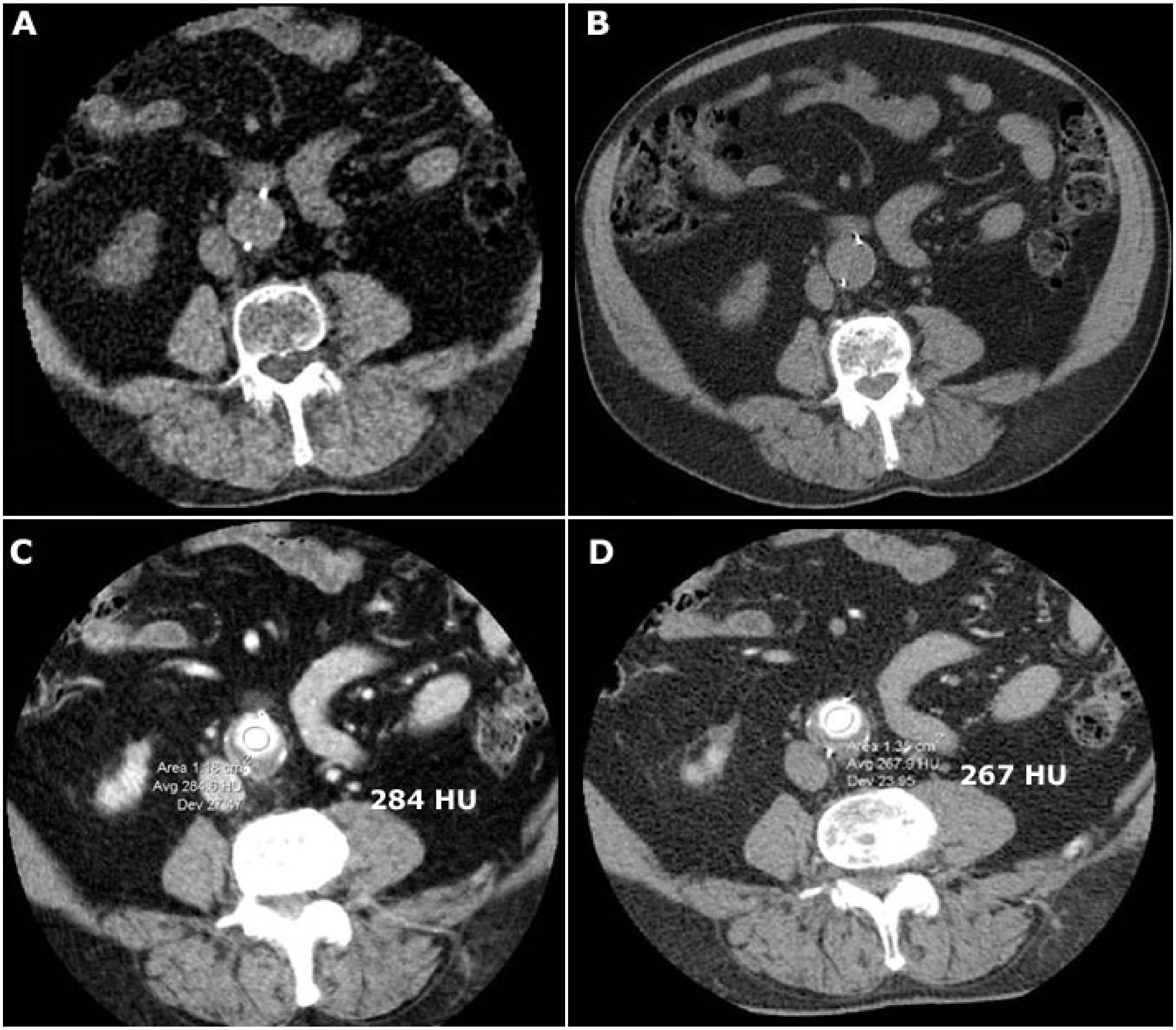

Figure 4. CT Angiography. Virtual unenhanced image **(A)** derived from venous phase multi-energy CT acquisition is comparable to true unenhanced **(B)** CT image. The attenuation value of the aorta on multi-energy venous phase 50 keV image **(C)** is similar to that of single energy (120 kVp) arterial phase acquisition **(D)**.

enhanced delayed venous phase. With multi-energy CT, it is possible to obtain the same information with one image acquisition in the delayed venous phase (Figure 4). Virtual non-contrast examination images can discriminate calcification within the aneurismal sac from endoleak. This practice of single image acquisition has major ramifications for radiation dose reduction in these patients, who require frequent followup surveillance imaging following EVAR.

Deep Vein Thrombosis Imaging

Pulmonary embolism (PE) is a well known sequela and a cause of morbidity and mortality secondary to deep venous thrombosis (DVT) involving lower extremities. A reliable diagnosis of DVT cannot be made based solely on clinical and lab findings. CT venography (CTV), which is often performed concurrently with a CTA for a PE examination, mandates optimal selection of technical parameters and timing of venous phase to achieve greater venous enhancement and enable venous clot detection. Despite protocol optimization efforts, adequate lower extremity venous enhancement is not always accomplished, often rendering these studies indeterminate.

With multi-energy CT, iodine maps or lower energy image data can increase the conspicuity of small dose iodine in the veins, thereby improving the quality of the CTV exam and increasing diagnostic confidence in rendering a DVT diagnosis.

CT Colonography (CTC) with Minimal or no Preparation

In CT colonography (CTC) examinations, multi-energy CT can facilitate distinction between a polyp and fecal material based on their attenuation differences at two energies. If validated and appropriately used, this benefit can potentially obviate the need for uncomfortable colonic preparation for CTC examinations.

Radiation Dose

Although the potential benefits of multi-energy CT are exciting, its utilization should be justified because the benefit of scanning multiple body regions, such as chest, abdomen and pelvis, may not outweigh the increase in radiation exposure associated with multi-energy imaging compared to a standard CT examination. However, if fewer acquisitions are necessary, then there will be an overall dose reduction compared to a standard examination. It should also be noted that many dose reduction techniques are in use at Mass General Imaging (see Radiology Rounds, February 2008, October 2009). Therefore, the DECT radiation doses are well within the American College of Radiology recommended dose range.

Scheduling

Multi-energy examinations are available only on the main Mass General campus. The decision to perform a multi-energy examination is generally made by a radiologist, but a special request for these examinations may be made through Cristy Savage, CT Technical Manager, at **617-724-8519** or Dushyant Sahani, M.D., Director of CT Imaging.

Further Information

For further questions on multi-energy CT, please contact Dushyant Sahani, M.D., Director of CT Imaging, Department of Radiology, Massachusetts General Hospital at **617-726-3937**.

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