Dual-energy KUB Radiographic Examination for the Detection of Renal Calculus

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**Rationale and Objectives:** The dual-energy radiographic technique has been proved to be clinically useful in the thorax. Herein, we attempt to apply this technique to the abdomen and pelvis in the context of renal colic.

**Materials and Methods:** The visibility of renal calculi were assessed using various dual energy peak kilovoltage combination radiographs applied to standard phantoms.

**Results:** This technique demonstrates a higher than acceptable radiation dosage required to optimize the image quality and the optimized diagnostic quality is inferior to that of the standard Kidneys, Ureters, and Bladder radiograph.

**Conclusions:** The dual-energy radiographic technique could not better identify the radiopaque renal calculi. Limiting technical considerations include the increased subcutaneous and peritoneal adipose tissue and the limited contrast between the soft tissue and underlying calculi.

**Key Words:** Renal calculus; dual energy; radiography.

Kidney stones affect up to 5%–10% of the general population (1) and are a common emergency presentation in developed nations. They have been associated with improved standards of living, the male sex, and a peak incidence at around 30 years of age (2). At least 50% of patients will have recurrences. Kidney stones vary in composition and are broadly categorized as calcium-containing stones that are radiopaque and noncalcareous stones including struvite and cystine which have variable radiographic opacity and conspicuity; pure uric acid stones are lucent. Radiologic evaluation plays an important role in determining the appropriate management (3).

In acute presentations of possible renal calculus, a low-dose unenhanced computed tomography (CT) of the abdomen and pelvis, which includes the Kidneys, Ureters, and Bladder (KUB), is currently the gold standard to assess for stone size, location, and possible complications. Even after treatment, a subset of patients will have recurrent calculi that can lead to chronic renal disease and significant morbidity. At our institution, patients with suspected or known recurrent urinary stone disease undergo at least a plain radiograph and/or a low-dose unenhanced multidetector CT. The low-dose CT examination is not benign and can impart ~3.2 mSv of radiation per scan versus 0.7 mSv from a plain radiographic KUB. Some patients will have undergone multiple CT examinations for recurrent stone disease. Considering that stones frequently first appear in patients of reproductive age, strategies to minimizing radiation exposure are desirable. A lower dose alternative is to obtain a plain radiograph KUB to assess for stones. However, this method is limited by the radio-opacity of the stone [only 59% of urinary stones are radiodense (4)], and often small stones are obscured by overlying soft tissue and bowel stool and gas (4), making this a low-sensitivity examination at 45%–59% (3,4).

**METHODS**

Dual-energy x-ray imaging (DEXI) has been shown in previous studies to enhance detectability of certain tissues by removing undesired background clutter caused by contrasting tissue types (5,6). Dual-energy chest radiographs are routinely obtained at some institutions. The basic principle behind DEXI is that various materials in the body, as a function of their atomic number, will demonstrate differential x-ray attenuation when exposed to two different x-ray energies. For example, bone will show a greater change in x-ray attenuation compared to soft tissue when imaged at low and high energies (peak kilovoltage). Theoretically, the two images can be combined to produce subtraction images in which materials of a given atomic number, such as soft tissue, can be selectively canceled (7). By doing so,
the “structured noise” of the image, which refers to noise from unwanted or undesired signals that decreases the conspicuity of subtle features, can be lessened and a high-contrast image of bone or bone-like structures remains. Specifically, three images are obtained: a soft tissue image from the low–peak kilovoltage energy, a bone image from the high peak kilovoltage, and a "standard" image from the average of the two energies. The high energy beam easily penetrates the body and results in low radiation absorption. At low energies, the contrast is high but the body penetration is very low resulting in a high dose to the patient.

The visibility of in vivo renal calculi was assessed using an abdominal phantom to control for patient factors such as abdominal girth, overlying bowel gas, and content or positioning. An abdominal phantom was constructed using two 10-cm silicon slabs to simulate the abdominal soft tissue. Three clusters of renal calculi collected from lithotripsy procedures were inserted between the two slabs. KUB radiographs were then acquired using a flat-panel digital system (Definium DR 8000; GE Healthcare, Waukesha, WI). The radiographic system includes an amorphous silicon indirect flat-panel detector. The detector has an image size of 41 \times 41 \text{ cm} with 200 \mu\text{m} pixels. Dual-energy images were acquired at multiple dual-exposure combinations at 120/80 kVp, 140/80 kVp, and 140/70 kVp with a 200-millisecond delay between the high- and low-energy exposures. The dual-energy examination consists of the standard digital anteroposterior radiograph which is the equivalent of an 80-kVp examination as well as the soft tissue image (bone subtracted) and the bone image (soft tissue subtracted). The entrance dose calculation was performed for all energy combinations and for the standard KUB radiograph using a 6-cc ion chamber (Accupro; Radcal Corporation, Monrovia, CA) which accounted for the back scatter. The effective dose was not calculated since the dual-energy spectrum could not be determined without the use of specialized algorithms (6). All images were evaluated using IMPAX viewing stations (AGFA Healthcare, Belgium) and were independently assessed by co-authors CP and PY.

RESULTS AND DISCUSSION

The energy combination that derived the most optimal soft tissue subtraction image for calcium detection was found to be a combination of 140 and 70 kVp (Fig 1). Phantom studies show that this is associated with a 61% (2.21 mGy) higher skin entry dose than a standard 80-kVp examination (1.37 mGy). The 140/80 kVp and 120/80 kVp examinations resulted in 35% (1.85 mGy) and 18% (1.62 mGy) increases, respectively.

Using the silicon abdominal phantoms to assess the quality of renal calculus contrast and detectability, none of the DEXI images was deemed to be more superior to the standard KUB examination for stone conspicuity and ultimately for renal calculus detection. The overall quality of the dual-energy abdominal radiographs was diagnostically inferior compared to the standard 80-kVp abdominal radiographs in the detection for renal calculus. Known renal stones present on the standard images were only faintly visible or not visible on the soft tissue subtraction images (Fig 2).

Several patient and physical factors are postulated to have contributed to the inferiority of the dual-energy image quality. First, there is a wide range of variability in the amount of abdominal subcutaneous and peritoneal fat which can significantly attenuate the energy spectra and also produce increased scatter radiation within the body. This can result in substantial degradation of the soft tissue subtraction image quality. This is of significance when the renal calculus often measures in the subcentimeter range, and the resulting images will have insufficient sensitivity to detect the small stones.

Second, the quality of the soft tissue subtraction images from the abdomen has substantially lower differential contrast than those obtained from the thorax because of the physical contrast characteristics, such as the atomic number and the density of the body compartments (eg, density of air, muscle, and calcium are 0.00129, 1.0, and 1.55 g/cm³, respectively).
Therefore, the difference in contrast between calcium and air is much more conspicuous than the difference between calcium and soft tissue. This makes detection of a small lung granuloma possible but a small renal calculus less likely.

In conclusion, however optimized, DEXI KUBs cannot overcome the inherent patient and physical limiting factors and the results do not support the use of dual-energy KUB in improving the clinical detection of renal calculi.

REFERENCES


Figure 2. A 58-year-old female with a history of renal calculi. (a) The dual-energy soft tissue subtraction image obtained at 140/70 kVp shows a small calculus in the right interpolar region. (b) The calculus is well visualized on the standard Kidneys, Ureters, and Bladder x-ray image.