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REVIEW

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Quantitation of stone burden: imaging advances

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Abstract The accurate diagnosis and quantitation of nephrolithiasis in patients with primary hyperoxaluria (PH) often directly impacts the medical and surgical management for individuals with both symptomatic and asymptomatic calculi. Traditionally, depiction of the size, location and appearance of urinary calculi has been provided by kidney, ureter and bladder plain film radiographs with or without tomography. Given advances in imaging technology there is a shift from conventional radiographs to cross-sectional imaging technology, namely unenhanced computed tomography (CT), CT urography, ultrasound and magnetic resonance imaging. These diagnostic techniques provide differing advantages and disadvantages for imaging stone disease. This review outlines imaging advances in the accurate diagnosis and quantitation of patients with metabolically active stone disease such as PH.

Keywords Primary hyperoxaluria · Stone burden · Quantitation · Diagnosis · Imaging

Introduction

In the past, quantitation of the extent of stone disease in asymptomatic patients with primary hyperoxaluria (PH) has traditionally been provided by kidney, ureter and bladder (KUB) with tomograms (Fig. 1) or renal ultrasound (Fig. 2) evaluation. A symptomatic patient with normal renal function often underwent an intravenous urogram (IVU) in order to characterize the cause and level of urinary tract obstruction (Fig. 3). Advances in CT technology have resulted in improved accuracy in both the diagnosis and quantitation of stone disease. The following article briefly reviews the background of current imaging techniques, including the advantages and disadvantages of each technique for the PH patient. Current technologic advances in CT imaging are also discussed, including the recent development of 64-channel scanners which offer improved resolution over earlier generation multichannel CT systems. The purpose of our brief review is to illustrate how these advances translate into improved quantitation of stone disease and improved care for PH patients.

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Imaging techniques—advantages and disadvantages

Conventional radiography

Conventional radiography, including both KUB with tomograms and IVU evaluation, have been the standard imaging techniques for patients with metabolic stone disease over the past several decades. The advantages of conventional radiography examinations have included the wide availability, low cost, reproducibility and a display form as traditionally viewed by radiologists and clinicians (e.g. nephrologists, urologists). The disadvantages of conventional radiography include the necessity for radiation exposure to the patient and the inconvenience of bowel preparation. In addition, linear tomography equipment is becoming increasingly rare in the modern radiology department. Further disadvantages of IVU include the time required for examination acquisition, varying from 30 min to several hours in patients with urinary tract obstruction. IVU also requires the administration of intravenous-iodinated contrast material which is contraindicated when there is known decreased renal function or a history of severe contrast reaction.

Fig. 1 Extensive bilateral intrarenal calculi consistent with medullary nephrocalcinosis of primary hyperoxaluria

Ultrasound

Renal ultrasound (US) is a readily available imaging technique which can detect the presence of stone disease in PH patients [1]. However, a negative US examination does not exclude intrarenal or ureteral calculi. The greatest advantage of sonographic evaluation, especially in the pediatric patient, is that it does not require ionizing radiation. However, US performs relatively poorly when determining the extent of stone disease compared to either KUB with tomograms [2] or CT evaluation, and has limited accuracy in the detection of small stones. Recent literature notes a 90% specificity in the detection of intrarenal calculi but only a 24% sensitivity when using unenhanced CT as a reference [3]. Quantitation of stone burden is difficult due to this poor reproducibility as well as significant operator dependence.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) has very limited application for the evaluation of stone disease since it cannot directly detect calcifications or stone material [4]. In addition, it is a relatively expensive examination, requires patient cooperation in breath-hold techniques and often has limited availability in acute emergency room evaluation.

Computed tomography

During the past decade, numerous publications have shown unenhanced CT to be the preferred imaging technique for imaging symptomatic urinary calculi [5–13]. Initial research using unenhanced CT in patients

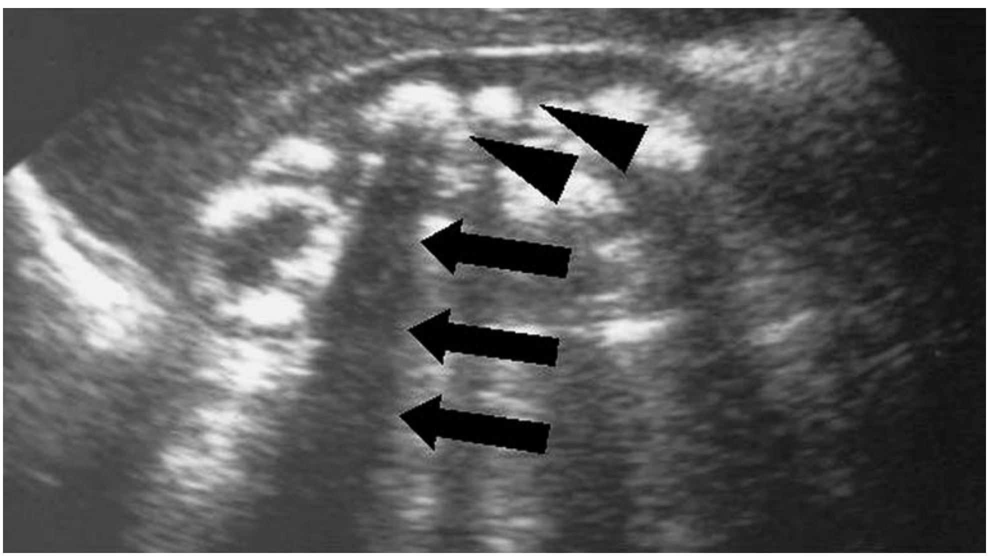

Fig. 2 Sagittal renal ultrasound demonstrating echogenic pyramids (*arrowheads*) and posterior acoustic shadowing (*arrows*) consistent with medullary nephrocalcinosis in a primary hyperoxaluria patient

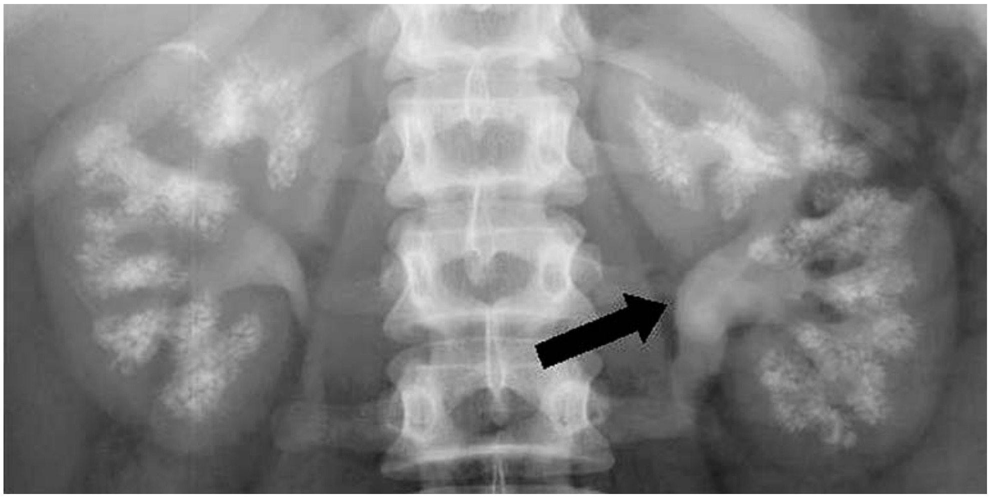

Fig. 3 IV urography with mild dilatation of the left intrarenal collecting system (*arrow*) consistent with obstruction from a small distal left ureteral calculus

with symptomatic urinary calculi demonstrated specificities of 96% and sensitivities of 97%. Current research shows sensitivities and specificities in the detection and characterization of ureteral calculi approaching 100%.

The wide acceptance of CT in the patient with symptomatic urinary calculi can be attributed to CT systems which allow the acquisition of examinations with increased resolution and speed. The quality and speed of current CT examinations have increased dramatically as technology has evolved from single-channel spiral CT systems (ca. 1990) to multichannel (4-, 8-, 10- and 16-channel) spiral systems (ca. 1998 through 2001). In 2004, 64-channel CT technology first became available. The current 64-channel CT scanners allow CT acquisition with the most accurate spatial resolution at the fastest speed. The spatial resolution refers to the smallest object (in mm) that can be accurately resolved with an imaging system. The 16-channel CT scanners have a spatial resolution in the transverse plan of 0.4 mm, but only 0.64–0.75 mm in the cephalocaudal or z-direction. The 64-channel CT system not only has a spatial resolution of 0.4 mm in the transverse x- and y-planes, but also a spatial resolution of 0.4 mm in the z-direction. Having equivalent resolution in the x-, y-, and z-directions is termed isotropic resolution. Isotropic resolution has important implications for quantitative analysis (such as metabolically active stone disease) since the current examinations have improved reproducibility in the accurate detection, quantification and depiction of submillimeter structures (such as intrarenal urinary tract calculi). The accurate quantification of metabolically active stone disease has important implications for therapeutic response and/or disease progression. The increased speed of scanning is also advantageous, especially in the pediatric patient, where a limited CT examination of the kidneys can be acquired with submillimeter slices in less than 5 s.

Unlike KUB or IVU examinations, a CT evaluation for stone disease does not require bowel preparation (Fig. 4), and newer technologies require lower radiation doses when compared to older scanners due to the more efficient use of the x-ray beam. The current 64-channel CT system can be equipped with automatic exposure control (AEC) systems that continuously modulate the x-ray tube current based on the patient's size and tissue density. The AEC method tailors the x-ray dose to the patient's size such that less dense body regions (e.g. lungs) and smaller patients (e.g. children) receive a lower radiation dose [14–17]. In a recent study, an approximate 20% reduction in radiation dose across all patient

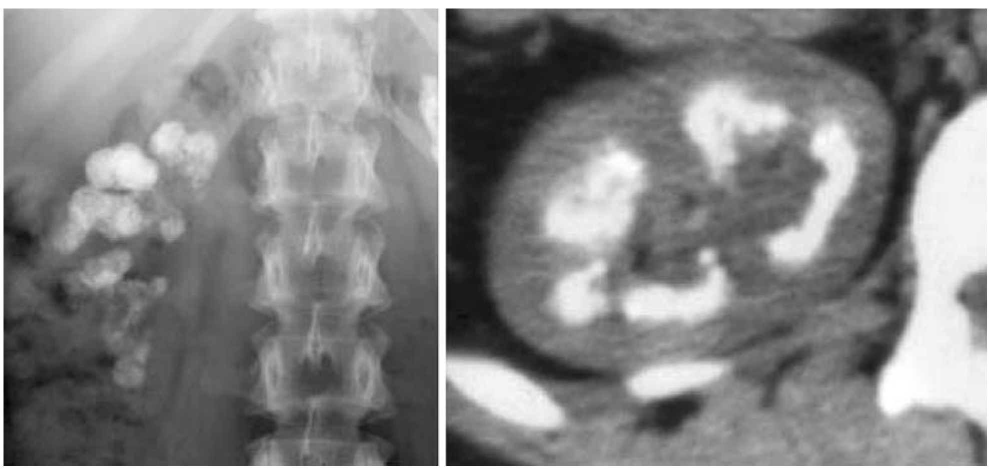

Fig. 4 KUB evaluation with extensive intrarenal calculi in a PH patient. Single axial CT through the midportion of the right kidney also demonstrates the extensive medullary calcifications

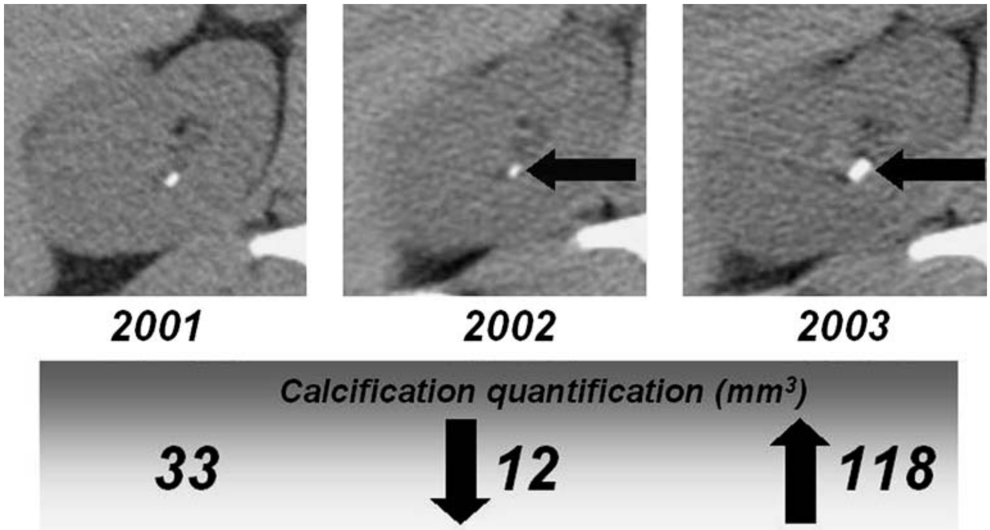

Fig. 5 Fifteen-year-old male with PH with intrarenal total stone volume of 33 mm^3 which initially decreased to 12 mm^3 with optimum medical management and increased to 118 mm^3 after discontinuing medical management

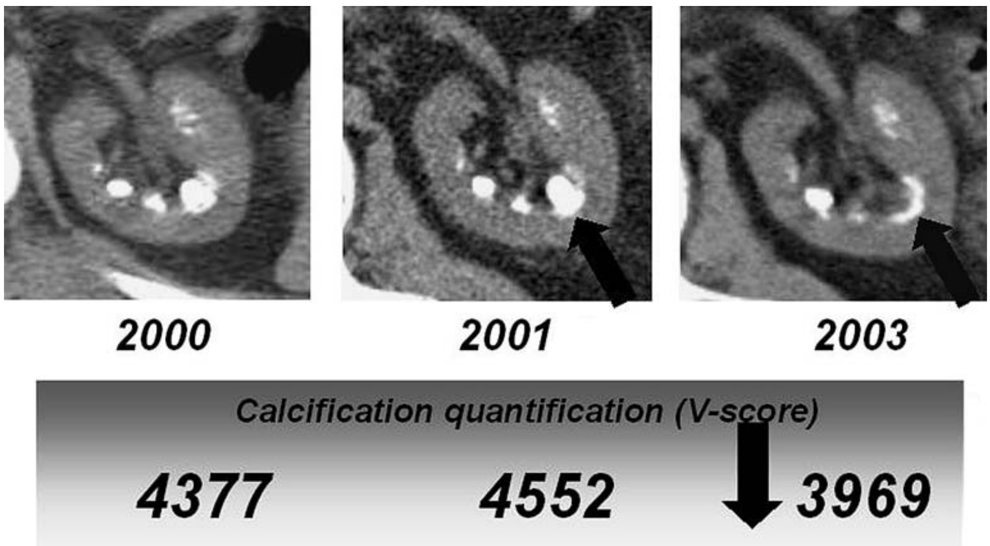

Fig. 6 Forty-year-old male with medullary nephrocalcinosis with intrarenal total stone volume of 4,377 mm^3 which increased slightly to 4,552 mm^3 1 year later and then decreased to 3,969 mm^3 after passing a ureteral stone

sizes using AEC was found compared to our prior manual method for the selection of CT techniques based on body size. For small adults or children, the dose reduction was approximately 50% when compared to standard technique factors used in CT exams [18].

Given the improved resolution of the detailed data sets, a volumetric display of CT acquisition can be actively reviewed in the optimum orientation including transverse, coronal, sagittal and oblique planes. Detailed volume-rendered 2 and 3-dimensional images can be generated using advanced post-processing techniques to optimally communicate important anatomic and pathologic findings between the radiologist, nephrologist and patient.

Future trends

Current advances in computer workstation analysis offer unprecedented, real-time post-processing capabilities. Rapid post-processing techniques have been developed for the quantitation of coronary arterial calcifications which allow the entire volume of CT data to be analyzed for the subset volume of calcium deposits as designated in mm^3 (V-score analysis). Limited CT images of the kidneys can be acquired using the high resolution technique at the lowest radiation dose available for CT evaluation and provide quantitative information with regard to the volumetric total of intrarenal calcifications during sequential CT studies obtained using identical techniques. This may provide important prognostic information for patients with PH in order to best determine responsiveness and progression of disease (Figs. 5, 6).

Conclusion

Current CT technology, specifically 64-channel scanners, provide the highest imaging resolution available for metabolically active stone disease in the PH patient. Current advances allow the scans to be obtained in a few seconds without the necessity of IV contrast material administration. Continued work with AEC and improved CT detector configurations will provide imaging of stone disease at the lowest achievable radiation dose. Reproducible post-processing techniques for high resolution CT imaging will likely provide accurate quantitation of metabolically active stone disease and improve the standard of care for patients with PH.

References

1. Diallo O, Janssens F, Hall M, Avni EF (2004) Type 1 primary hyperoxaluria in pediatric patients: renal sonographic patterns. Am J Roentgenol 183: 1767
2. Vrtiska TJ, Hattery RR, King BF, Charboneau JW, Smith LH, Williamson BJ et al. (1992) Role of ultrasound in medical management of patients with renal stone disease. Urol Radiol 14: 131
3. Fowler KA, Locken JA, Duchesne JH, Williamson MR (2002) US for detecting renal calculi with nonenhanced CT as a reference standard. Radiology 222: 109
4. Kawashima A, Glockner JF, King BFJ (2003) CT urography and MR urography. Radiol Clinics North Am 41: 945
5. Levine JA, Neitlich J, Verga M, Dalrymple N, Smith RC (1997) Ureteral calculi in patients with flank pain: correlation of plain radiography with unenhanced helical CT. Radiology 204: 27
6. Assi Z, Platt JF, Francis IR, Cohan RH, Korobkin M (2000) Sensitivity of CT scout radiography and abdominal radiography for revealing ureteral calculi on helical CT: implications for radiologic follow-up. Am J Roentgenol 175: 333
7. Smith RC, Rosenfield AT, Choe KA, Essenmacher KR, Verga M, Glickman MG et al. (1995) Acute flank pain: comparison of non-contrast-enhanced CT and intravenous urography. Radiology 194: 789
8. Smith RC, Verga M, Dalrymple N, McCarthy S, Rosenfield AT (1996) Acute ureteral obstruction: value of secondary signs of helical unenhanced CT. Am J Roentgenol 167: 1109
9. Fielding JR, Steel G, Fox LA, Heller H, Loughlin KR (1997) Spiral computerized tomography in the evaluation of acute flank pain: a replacement for excretory urography. J Urol 5: 2071
10. Chen MYM, Zagoria RJ (1999) Can unenhanced helical computed tomography replace excretory urography for evaluation of patients with acute urinary tract colic? J Emerg Med 17: 299
11. Niall O, Russell J, MacGregor R, Duncan H, Mullins J (1999) A comparison of noncontrast computerized tomography with excretory urography in the assessment of acute flank pain. J Urol 161: 534
12. Yilmaz S, Sindel T, Arslan G, Ozkaynak C, Karaali K, Kabaalioglu A et al. (1998) Renal colic: comparison of spiral CT, US and IVU in the detection of ureteral calculi. Eur Radiol 8: 212
13. Takahashi N, Kawashima A, Ernst RD, Boridy IC, Goldman SM, Benson GS et al. (1998) Ureterolithiasis: can clinical outcome be predicted with unenhanced helical CT? Radiology 208: 97
14. Greess H, Nomayr A, Wolf H, Baum U, Lell M, Bowing B et al. (2002) Dose reduction in CT examination of children by an attenuation-based on-line modulation of tube current (CARE Dose). Eur Radiol 12: 1571
15. Tack D, De Maertelaer V, Gevenois PA (2003) Dose reduction in multidetector CT using attenuation-based online tube current modulation. Am J Roentgenol 181: 331
16. Kalra MK, Maher MM, Kamath RS et al. (2004) Sixteen-detector row CT of abdomen and pelvis: study for optimization of z-axis modulation technique performed in 153 patients. Radiology 233: 241
17. Kalra MK, Maher MM, Toth TL et al. (2004) Comparison of z-axis automatic tube current modulation technology with fixed tube current CT scanning of abdomen and pelvis. Radiology 232: 347
18. McCollough CH, Kofler J, Zink F (2004) Hot topic: the dose consequences of new CT technology: evaluation of AEC and dose efficiency from 4 to 64-slice systems. RSNA Chicago, November 2004.