Computed Tomography of Urinary Calculi

Michael P. Federle[1]
Jack W. McAninch[2]
Jay A. Kaiser[3]
Philip C. Goodman[1]
John Roberts[2]
Jay C. Mall[3]

Computed tomography (CT) was used in the evaluation of nine patients with nonopaque calculi in the upper urinary tract. In each case the calculus was identified as a very high density object (370–586 Hounsfield units) with calcium oxalate and cystine stones having somewhat higher attenuation values than uric acid or xanthine stones. The differentation between calculi and other "radiolucent" filling defects was readily made since calculi had much higher attenuation values than blood clot or neoplasm. CT of the upper urinary tract may obviate the need for more invasive procedures such as retrograde pyelography when nonopaque filling defects require differentiation.

The problem of differential diagnosis of radiolucent filling defects in the upper urinary tract has long been a challenge for urologists and radiologists. Nonopaque calculi, blood clots, papillomas, and malignant tumor are usually considered in the differential diagnosis. Various methods have been used to distinguish them, including excretory urography, retrograde pyelography, and retrograde passage of opaque ureteral catheters and biopsy brushes. These techniques have the disadvantage of being relatively nonspecific and/or invasive, with retrograde catheterization procedures carrying the risks of perforation and infection. The advent of computed tomography (CT) has provided a definite advance in the diagnostic approach to this problem. Two brief reports on a total of five patients have indicated the potential for CT to accurately identify uric acid calculi and distinguish these from blood clots and primary tumor [1, 2]. We report nine patients with calculus disease, including some types of calculi whose CT appearance has not previously been described. Both in vivo and in vitro CT studies of calculi were performed in addition to detailed chemical analysis. CT can unequivocally demonstrate urinary calculi and may suggest the composition of the calculus based on characteristic CT attenuation values.

Materials and Methods

Review of the clinical material of two hospitals (a county institution of 425 beds and a community hospital of 150 beds) revealed nine cases of calculi of the upper urinary tract in which CT scans were obtained. All patients had excretory urography preceding the CT scan and four patients had retrograde pyelography without a definite diagnosis being established. In four cases, retrograde pyelography was deferred because of the information obtained through CT scanning. The nine patients had a total of 10 CT studies, all performed on General Electric 8800 CT-T scanners. In vivo scans were generally obtained as contiguous 1 cm sections, although 5 mm collimation was used to minimize partial volume averaging for smaller stones. In vitro scans of calculi were obtained after placing the stones inside a tissue-equivalent CT phantom. Proof of calculus disease in each case consisted of spontaneous passage or surgical removal of at least one stone which was then subjected to chemical and crystallographic analysis at specialized laboratories. The attenuation values listed were the average of several measured by an electronic cursor that uses a computer program to analyze a certain region of interest on the CT scans.

Received March 31, 1980; accepted after revision October 6, 1980.

[1] Department of Radiology, University of California, San Francisco, and San Francisco General Hospital, 1001 Potrero Ave., San Francisco, CA 94110. Address reprint requests to M. P. Federle.

[2] Department of Urology, University of California, San Francisco, and San Francisco General Hospital, San Francisco, CA 94110.

[3] Department of Radiology, Ross General Hospital, Ross, CA 94957.

***AJR* 136:255–258, February 1981**
0361-803X/81/1362-0255 $00.00

TABLE 1: **CT of Urinary Calculi**

Case No.	Age, Gender	Density on Plain Film	Representative CT Attenuation Value (in vivo) (H)	Type of Calculus
1	60 yr, F	Nonopaque	346	Uric acid
2	53 yr, M	Nonopaque	390	Uric acid with calcium oxalate dihydrate
3	66 yr, M	Nonopaque	370	Uric acid
4	61 yr, F	Nonopaque	400	Uric acid
5	66 yr, M	Nonopaque	Not measured	Uric acid
6	14 mo, F	Nonopaque	391	Xanthine
7	50 yr, F	Nonopaque	398	Uric acid
8	42 yr, F	Low	586	Cystine
9	35 yr, F	Low	510	Calcium oxalate

Note.—CT attenuation values are on a scale of 1,000 H.

Results

Of the nine patients in our series, five had pure uric acid calculi, one had predominantly uric acid with some calcium oxalate dihydrate, one xanthine, one cystine, and one calcium oxalate. The uric acid stones had CT attenuation values of 346–400 Hounsfield units (H) on a +/− 1,000 scale. The xanthine stone had a similar density of 391 H, while the cystine stone measured 586 H and the calcium oxalate 510 H. These attenuation values were those obtained on the in vivo CT studies, although similar values were obtained for each of the four basic types of stones on the in vitro scans. The results of the CT scans and final diagnoses are summarized in table 1. Two cases are selected as representative.

Representative Case Reports

Case 1

A 60-year-old woman had left flank pain for 24 hr. She was known to have congenital absence of the right kidney and had chronic borderline renal function, partly attributed to poorly controlled hypertension. Laboratory tests on admission revealed elevated BUN, creatinine, and serum uric acid. An excretory urogram obtained on admission showed prompt but suboptimal concentration and excretion from the solitary left kidney (fig. 1A). The ureter was dilated to a tapered point near the ureterovesical junction. No calculus was identified on either the scout film or delayed films from the excretory urogram.

Because of strong clinical suspicion of ureteral calculus, a retrograde pyelogram was obtained (not shown) which revealed a single large filling defect at the level of the pelvic brim. At this point, the clinical diagnosis was uric acid calculus, and two perfusion catheters were placed in the ureter for perfusion of bicarbonate solution to dissolve the stone.

Renal function and clinical status improved for several days, but then gradually deteriorated over the following week. A repeat retrograde pyelogram (not shown) showed a tapered obstruction of the ureter at the pelvic brim, but no filling defect within the ureter. It was uncertain whether there was still a stone present, or spasm and obstruction of the ureter due to stone passage and the indwelling catheters.

A CT scan was obtained without intravenous contrast material since the patient had become essentially anuric with markedly impaired creatinine clearance. The scan demonstrated a dense ureteral calculus at the pelvic brim (fig. 1B) and a second ureteral calculus 5 cm proximal to the first, which had not been seen or suspected on the previous urograms or retrograde pyelograms (fig. 1C).

After CT, a ureterolithotomy was performed and two 1.5 cm calculi were removed. Postoperatively the patient had a marked diuresis and rapid clinical improvement. Laboratory analysis of the two calculi revealed that both were pure uric acid in a protein matrix.

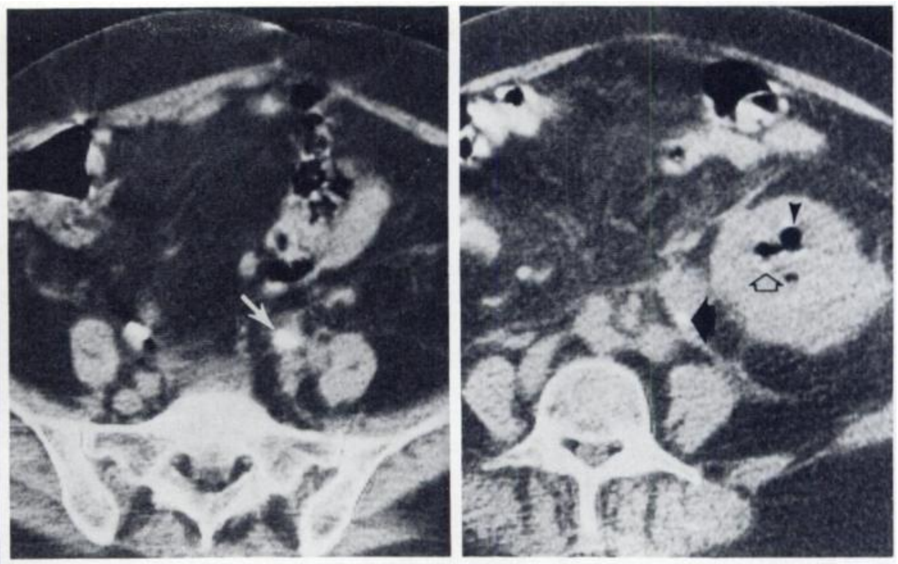
Case 6

A 15-month-old girl was evaluated for recurrent urinary tract infections. She was well until about 1 month before admission when she developed the first of two urinary tract infections accompanied by fever, with *E. Coli* cultured from the urine. An excretory urogram revealed a radiolucent filling defect in the left renal pelvis, with no obstruction (figs. 2A and 2B). A renal calculus was considered most likely although there was no clinical or laboratory evidence of metabolic or hematologic disorder, nor were any medications being taken. Additional considerations included a renal papilloma. A retrogade pyelogram was not attemped due to the patient's age. A limited CT scan was obtained through the kidneys and clearly revealed a relatively high-density calculus in the left renal pelvis (fig. 2C). The patient was then admitted for elective pyelotomy with removal of the stone, which consisted entirely of xanthine on analysis.

Discussion

The problem of differentiating nonopaque calculi from other radiolucent filling defects in the upper urinary tract has been a difficult one. About 5%–8% of calculi are nonopaque or of low density, consisting mostly of uric acid or urate stones, but also including xanthine, some cystine and matrix stones, and about 2% of struvite calculi [3, 4]. The classic appearance of a nonopaque stone is a negative shadow or filling defect in the urographic medium, however, a stone may also closely simulate a ureteral stricture or primary ureteral tumor. In the past, exploratory laparotomy has occasionally been necessary to make the distinction, and unfortunately some kidneys have been resected for presumed ureteral malignancy when calculus disease was actually responsible for ureteral obstruction [5]. Since uric acid, xanthine, and cystine stones may sometimes be treated nonoperatively by high fluid intake and alkalinization of the urine, it becomes even more important to make an accurate diagnosis by a noninvasive method whenever possible.

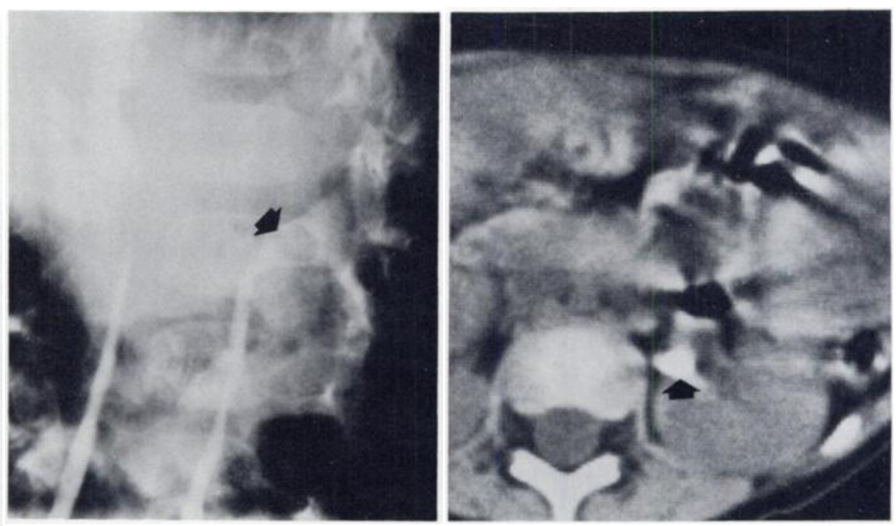
A



B C

Fig. 1.—Case 1. **A**, Admission excretory urogram. Solitary left kidney. Calyces and ureter dilated down to tapered point near ureterovesical junction. No calculus or filling defect identified. **B**, Section through lower ureter. High density calculus (*arrow*) corresponds to filling defect seen on retrograde pyelogram (not shown). Similar calculus was identified within ureter 5 cm proximally. (High density focus on opposite side is retained barium). Attenuation value of uric acid calculus was 346 H. **C**, Section through renal hilus. Air in calyces (*arrowhead*) due to previous ureteral catheterization. Several small areas of high density (*arrows*) represent small uric acid calculi in calyces and proximal ureter.

A



B C

Fig. 2.—Case 6, 15-month-old girl. Anteroposterior (**A**) and oblique (**B**) films from excretory urogram. Filling defect within renal pelvis (*arrow*). **C**, CT section through renal pelvis. High density calculus in left renal pelvis (*arrow*). Xanthine stone removed at surgery.

As is well known, CT has very high density resolution capability. Using CT, one can distinguish density differences of as little as 0.5% while plain film radiography requires a density difference of about 5%. Thus even noncalcified stones appear much denser than surrounding soft tissues on CT. Additional difficulties in plain film diagnosis of ureteral stones are obscuration by overlying bowel gas or bony structures, which are obviated by the tomographic nature of CT.

We were somewhat surprised by the very high density that all stones exhibited on CT regardless of their mineral content or appearance on plain films. In fact, all stones appeared "pure white" on CT scans, with their difference in density only distinguishable by actually measuring CT attenuation values. One factor that may have been partly responsible for extremely high CT numbers in some cases was the previous administration of urographic contrast medium during excretory urography or retrograde pyelography. We hypothesized that there might be some absorption of contrast medium by the stones, which contributed to the apparent density when CT scans were later obtained.

To test this hypothesis we made in vitro scans of cystine stones in a water bath. The average CT number before exposure to contrast medium was 585 H (on a ± 1,000 scale). After immersing the stones in dilute contrast material (2 ml of Conray 60 and 20 ml of water) for 1 min, the stones were washed and reimmersed in plain water. Repeat scanning revealed an increase in the average CT number to 850 H. Thus, even transient exposure to contrast medium in vivo during urography or pyelography may make stones appear more dense on subsequent CT scans. However, it must be pointed out that even in cases where no contrast material had been given, CT was able to clearly distinguish stones from surrounding soft tissues.

Uric acid calculi are the most radiolucent type commonly encountered and we have studied several such stones in vitro. Attenuation values in excess of 300 H were found in each instance, even when there had been no exposure to contrast media. High CT attenuation is not indicative of calcium content in the stones, since pure uric acid, xanthine, and cystine stones are all very dense. Calcium-containing stones are usually even more dense, and are commonly identifiable on plain radiography. Since uric acid, cystine, and xanthine stones do not contain metallic or other high atomic number elements, their high attenuation values must be due to high physical density.

There is some discrepancy between the attenuation values of stones in this series and those reported previously. The only previous study that measured the density of urinary calculi reported values of 50–120 "CT units," roughly equivalent to 100–240 H, for three uric acid calculi [1]. The authors did not indicate how these values were obtained, but it was probably by means of a "blink mode" used on earlier generation CT scanners. This method may not be as accurate as the computer program used in our series.

The small size of some ureteral calculi makes detection on plain radiographs difficult. This may also prove to be a problem on CT, although we successfully demonstrated calculi as small as 2–3 mm, some of which were uric acid stones (fig. 1C). Two factors to be considered when scanning for calculi are partial volume averaging and accuracy of CT slice location. A small stone occupying less than the entire thickness of the CT slice will have its density averaged together with that of overlying and underlying tissues. Thus, it could appear as a nonspecific soft tissue density. This problem can be alleviated by use of thin-section collimators on the CT scanner. We routinely scan with a 10 mm collimator, but switch to a 5 mm collimator to examine any suspicious areas such as narrowed ureteral segments for possible small calculi.

To eliminate the possibility of not scanning through a ureteral lesion completely, contiguous CT sections must be obtained. The patient must also be cautioned against even slight changes in position on the scanning table. A newer technical innovation that may facilitate accurate location of CT sections is the lateral localizer image. This provides a computer-generated radiograph of the patient oriented like a typical anteroposterior or lateral radiograph. Using this as a "scout film" one can precisely localize the level of subsequent CT sections, and can then obtain finely collimated contiguous sections through areas of concern.

While we did not undertake a large prospective study of the accuracy of CT in distinguishing stones from other radiolucent filling defects, we encountered a small number of cases that may be representative. In three cases of transitional cell carcinoma of the ureter, CT revealed small homogeneous soft tissue masses with attenuation values of 30–60 H. In another diabetic patient with *Candida* fungus balls obstructing the renal pelvis, CT showed a mottled soft tissue mass of about 20–40 H. A single report of the CT appearance of transitional cell carcinoma describes three cases with soft tissue masses of 15–20 "CT units" (about 30–40 H) [1]. Blood clots and other tumors have similar attenuation values, and these too are easily distinguished from urinary calculi, which are consistently more dense than any other noncalcified structure in the body.

REFERENCES

1. Segal AJ, Spataro RF, Linke CA, Frank IN, Rabinowitz R. Diagnosis of nonopaque calculi by computed tomography. *Radiology* **1978**;129:447–450
2. Tessler AN, Ghazi MR. Case profile: computerized tomographic assistance in diagnosis of radiolucent calculi. *Urology* **1979**;6:672–673
3. Herring LC. Observations on the analysis of ten thousand urinary calculi. *J Urol* **1962**;88:545–562
4. Prien EL. The analysis of urinary calculi. *Urol Clin North Am* **1974**;1:229–249
5. Emmett JL, Witten DM. *Clinical Urography*, 3rd ed. Philadelphia: Saunders, **1971**
6. Sagel SS, Stanley RJ, Levitt RG, Geisse GG. Computed tomography of the kidney. *Radiology* **1977**;124:359–370