EVALUATION OF THE URETER AND URETEROVESICULAR JUNCTION USING HELICAL COMPUTED TOMOGRAPHIC EXCRETORY UROGRAPHY IN HEALTHY DOGS

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Abdominal computed tomography (CT) using a protocol designed for evaluation of the ureters was performed on six normal purpose-bred research dogs. After noncontrast CT, a postcontrast scan was performed 3 min post midpoint of injection of 400 mgI/kg body weight of diatrizoate meglumine/ sodium. Ureteral and ureterovesicular junction anatomy were readily assessed with minimal patient preparation. The ureters were similar in size to reported values and the renal pelvis, ureter, and ureterovesicular junction were easily identified on both noncontrast and contrast-enhanced scans. There was a significant relationship between bladder volume and interureterovesicular junction distance but not between bladder volume and ureterovesicular junction to internal urethral orifice distance. A reliable bony landmark for the identification of the internal urethral orifice could not be determined. The results of this preliminary study of normal anatomy should facilitate the clinical use of CT in the evaluation of ureteral disease (e.g., ureteral ectopia). *Veterinary Radiology & Ultrasound, Vol. 44, No. 2, 2003, pp 155–164.*

Key words: canine, dog, ureter, computed tomography, CT, excretory urography, computed tomographic excretory Urography, CTEU.

Introduction

THE MOST COMMONLY used modality for evaluating the ureter in animals is excretory urography (EU). Evaluation of the ureterovesicular junction for disorders such as ureteral ectopia, however, can be time consuming and difficult to interpret. At the Tufts University School of Veterinary Medicine, the standard technique[1] is modified to include pneumocystography, which has been described to improve the evaluation of the ureterovesicular junction.[2] Even with pneumocystography, however, evaluation of the ureterovesicular junction can be difficult, and a diagnosis cannot always be made with confidence.

Computed tomography (CT) has been used in humans to evaluate the upper urinary tract and in many institutions is the modality of choice for evaluation of kidney masses[3–5] and urolithiasis.[6–10] Recently, two CT excretory urography techniques have been found to be as good or better than EU for visualizing the collecting system and ureter.[11,12] CT excretory urography has been used to diagnose ureteral ectopia in people.[13,14]

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CT evaluation of the ureter has been described in animals to investigate incontinence in the dog and llama.[15,16] The optimal contrast medium dosage and time of image acquisition for visualizing the ureter in dogs using CT has been described.[17] Beginning the scan 3 min after injection of contrast medium at a dose of 400 mg iodine per kilogram body weight (mgI/kg) was recommended.

In the authors' experience with clinical patients, CT of suspected ureteral ectopia may be difficult to interpret. We felt that a familiarity with the appearance of the normal ureter and ureterovesicular junction would aid in interpretation. The purpose of this study was twofold. The first was to determine whether, with a relatively simple protocol, the entire ureter could be visualized reliably and consistently. The goal was to develop a protocol that would allow visualization of the ureter with minimal patient preparation. The optimal technique could be performed easily in clinical patients without urinary bladder catheterization, contrast cystography, cleansing enemas, or standardization of bladder volume. The second purpose was to describe the appearance of the normal ureter and ureterovesicular junction and to identify some of the variations or potential pitfalls associated with the technique.

Materials and Methods

Seven (two male, five female) purpose-bred research dogs aged 4–7.5 years and weighing 21.2–30.2 kg were used. The approval of the Institutional Animal Care and Use Committee was obtained before testing. Dogs were screened for signs of systemic and urinary tract disease by means of a physical examination and clinical laboratory data, including a blood packed cell volume, serum total protein, Azostix®* BUN, blood glucose, urinalysis and urine culture. In one dog, a urine protein–creatinine ratio was required to investigate mild proteinuria, the results of which were within normal limits, indicating that the detected proteinuria was not caused by significant renal disease. Dogs were fasted for 12 h before the procedure. Two to four hours before the CT, the dogs allowed to urinate and defecate outdoors. An indwelling intravenous catheter was placed in a peripheral vein. Pre-anesthetic sedation with a combination of butorphanol (0.2 mg/kg), acepromazine (0.05 mg/kg), and glycopyrrolate (0.01 mg/kg) was administered intramuscularly to all dogs. Anesthesia was induced with thiopental and maintained with isoflourane. Maintenance level fluids (lactated Ringer's solution at 10 mL/kg/h) were administered to all dogs during anesthesia.

The dogs were positioned on the patient couch in ventral recumbency. An abdominal scan was performed from a level cranial to the kidneys to the tuber ischii. A helical CT scanner† was used to obtain 5-mm thick slices at an index of 3 mm with a pitch factor of 1.25. Matrix size was 512 × 512 and tube factors were 120 kVP and 250 mA. A displayed field of view of 300 mm was used in all dogs. A second scan was performed with a displayed field of view of 200 mm from the cranial aspect of the urinary bladder to the tuber ischii. Both scans were repeated following a bolus intravenous injection of diatrizoate meglumine/sodium solution (Renocal-76®‡) at a dosage of 400 mgI/kg. Scanning was initiated 3 min after the midpoint of injection. A balloon catheter was then placed into the bladder and the balloon inflated with room air. The catheter was pulled until resistance was met, indicating that the balloon was in the bladder neck. A third postcontrast scan using a 200 mm displayed field of view was performed from the bladder to the tuber ischii. This was done to provide a landmark for the location of the bladder neck if it could not be precisely localized on the other scans. The bladder was not emptied between scans.

Ureteral diameter measurements were made 2 cm caudal to the renal pelvis, 2 cm cranial to the ureterovesicular junction, at the midpoint between the 2, and at the level of the ureterovesicular junction. The measurements were made on the first scans (large displayed field of view extending from the kidneys to the tuber ischii) of both pre- and postcontrast studies. Three measurements were made of the minimal dimension of the ureter and the results averaged to account for minor caliper placement inconsistencies. The narrowest dimension was measured to assure that an oblique section of the tubular ureter did not result in falsely increased values. Measurements of the maximal bladder width and height at the ureterovesicular junction were also obtained, and the distance between the entrances of the two ureters into the bladder. The most consistent landmark for making this measurement was the apex of the "hook" formed as the ureter turned to enter the bladder wall (Fig. 1). On the precontrast images, if this hook could not be identified, the measurement was made at the level of the ureter's confluence with the bladder. The distance from the ureterovesicular junction to the internal urethral orifice was measured and referenced to the bladder volume/kg body weight to see if bladder volume affected this distance. The level of the internal urethral orifice was determined on axial slices in females as the slice caudal to which the diameter of the bladder neck/urethra remained constant, or in males where it increased due to confluence with the prostate gland. This level was identified and related to the first slice in which the bony pubic symphysis could be identified to see if the latter could be used as a landmark for identification of the internal urethral orifice. All measurements were made using dedicated software.§

Linear regression analysis was performed to assess for statistically significant correlations between bladder volume and the following: inter-ureterovesicular junction distance; distance from the ureterovesicular junction to the internal urethral orifice; and distance from the internal urethral orifice and the cranial brim of the pubis. Significance was defined as a p value of < 0.05. These analyses were performed to determine whether the bladder volume would affect the appearance of the local anatomy and influence the interpretation of clinical studies, necessitating standardization of bladder volume.

Results

One complete study was performed on each of seven dogs, of which six were used for data acquisition. One dog had an idiosyncratic reaction to the contrast medium with delayed excretion of contrast medium and was consequently excluded.

Mean precontrast ureteral diameter was 2.03 mm (standard deviation 0.32, range = 1.33–2.72 mm). Mean postcontrast ureteral diameter was 2.47 mm (standard deviation = 0.47, range = 1.51–3.48 mm). Contrast medium was absent from measured points on seven of the 36 postcontrast measurements (19%).

The ureters exited the renal pelvis and coursed caudome-

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†Picker Venue 5000, Phillips Medical Systems, N.A., Bothell, WA 98041-3003.

‡Bracco Diagnostics, Princeton, NJ, 08903.

§Voxel-Q software version 4.1 Phillips Medical Systems, N.A., Bothell, WA 98041-3003.

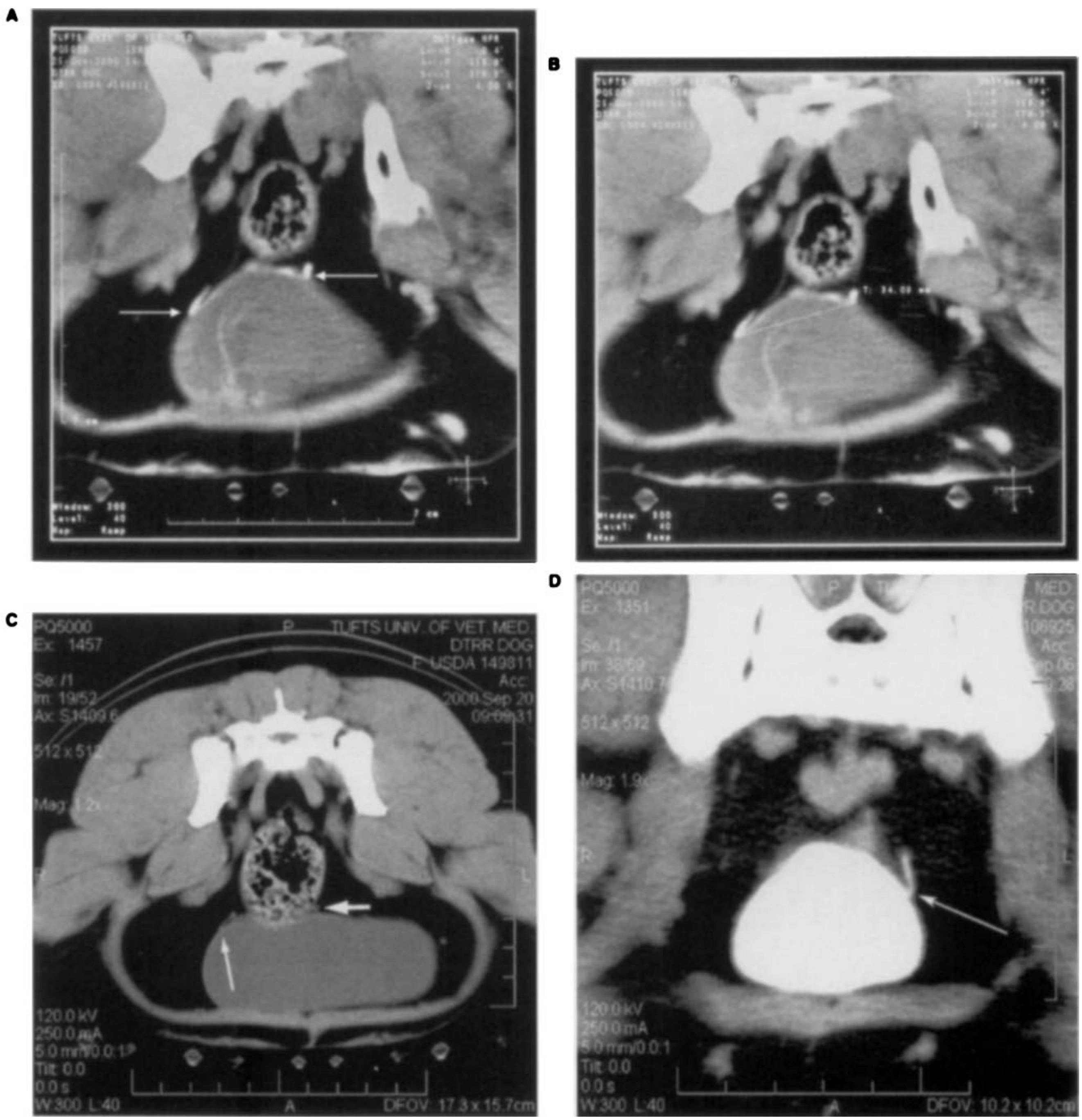

FIG. 1. Oblique multiplanar reconstructed CT images (a and b) and transverse images (c and d) of the bladder neck and trigone region in which the typical appearance of the ureteral entrance into the bladder can be seen. (a) Note the hook formed as the ureters change direction to enter the bladder wall (arrows). (b) The apex of this hook was used as a reliable landmark for identifying the entrance of the ureters into the bladder wall. This hook could be seen on both precontrast images (c, thin arrow) and when the bladder was full of contrast medium (d). The hooks of the right and left ureter were not typically in the same image, requiring multiplanar reconstructed images for measurement (c, thin arrow = right ureteral hook, wide arrow = left ureter). The right side of the dog is on the left of the image.

dially (Fig. 2). On the precontrast scan, there was adequate visualization of the ureters from the pelvis to the level of the deep circumflex iliac arteries in five dogs (Fig. 3a). Because the ureters coursed medially, they were obscured by confluence with surrounding structures (e.g., caudal great vessels, colon). This occurred in all six scans at the level of the aortic bifurcation (Fig. 4a). The length over which the ureter was obscured ranged from 1.2–1.6 cm in five dogs. In the sixth dog, the right ureter was obscured from 2.7 cm cranial to the deep circumflex iliac artery to just cranial to the

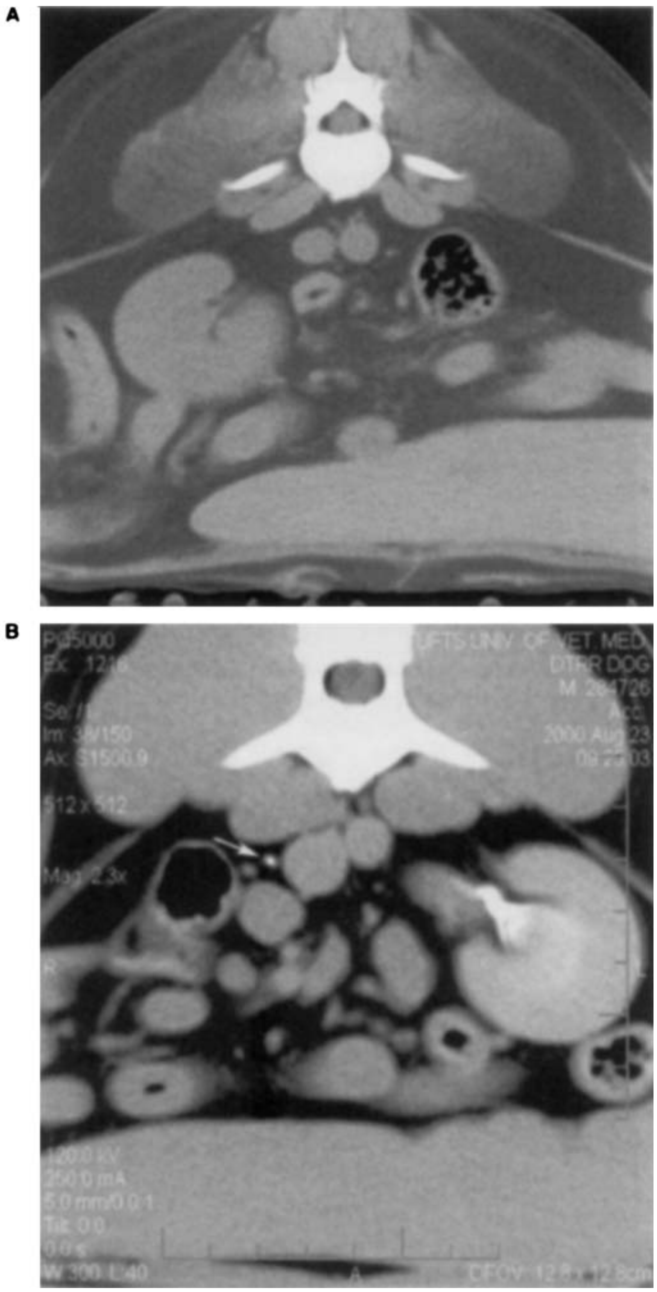

FIG. 2. Precontrast (a) and postcontrast (b) transverse CT images of the ureters at the level of the renal pelvis. The right pelvis and proximal aspect of the right ureter are seen in (a) along with the left ureter, seen adjacent to the aorta (in this dog, the left kidney was cranial to the right). In (b) (different dog), the left renal pelvis and proximal ureter are opacified, and contrast medium can be seen in the right ureter (arrow). The right side of the dog is on the left of the image.

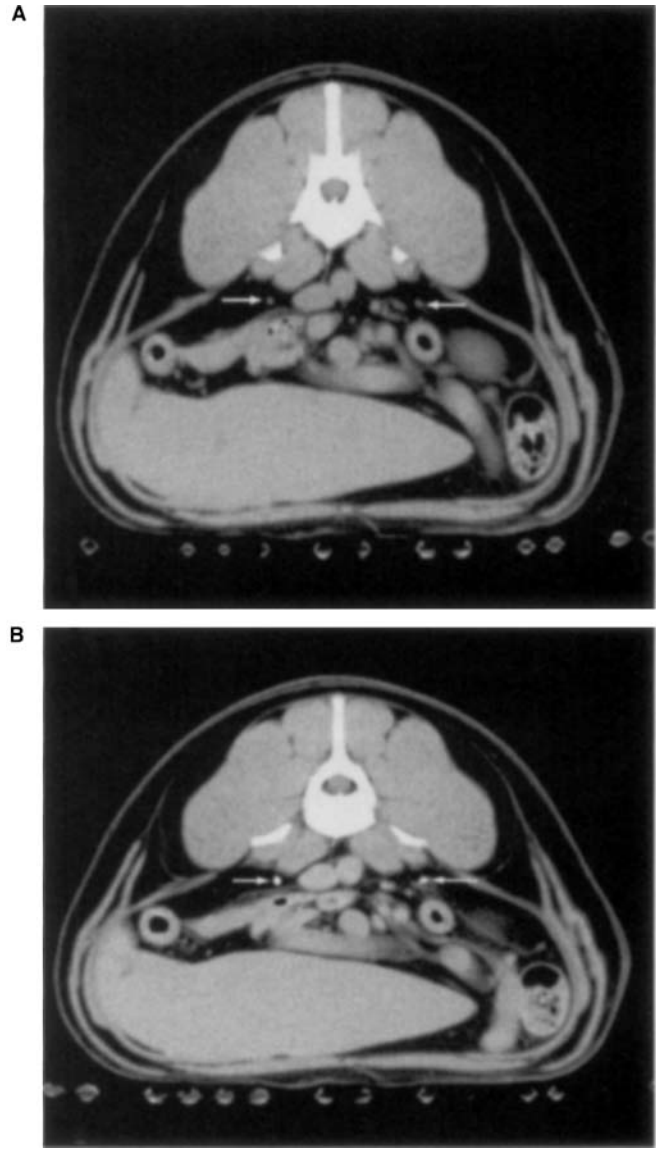

FIG. 3. Precontrast (a) and postcontrast (b) transverse images of the mid-abdomen. The ureters can be distinctly identified in this region (arrows). The right side of the dog is on the left of the image.

trigone, over a distance of 11.1 cm. The loss of distinct visualization of the ureters prevented measurement on only 2 of the 36 precontrast data collection points. Because the ureters coursed caudoventrally from the level of the aortic bifurcation, they were easily identifiable in most dogs (Fig. 5). As they coursed around the colon to the bladder, one or both lay adjacent to the colon on three precontrast scans, preventing discrete visualization (once, obscuring both ureters and twice obscuring only the left ureter; Fig. 4b). On all postcontrast scans, measurements and adequate visualization of the entire length of the ureter were possible. Although contrast medium was absent from seven of the postcontrast data points, the ureters in these locations were visible as in the precontrast study. At the data points where the ureter was not measurable on the pre-contrast images (2/36), the ureters were distinct on the postcontrast images because of the presence of contrast media in the ureteral lumen.

The entrance of the ureter into the bladder was characterized by a "hook" made as the ureter turned from its ventrolateral course to run dorsomedially through the blad-

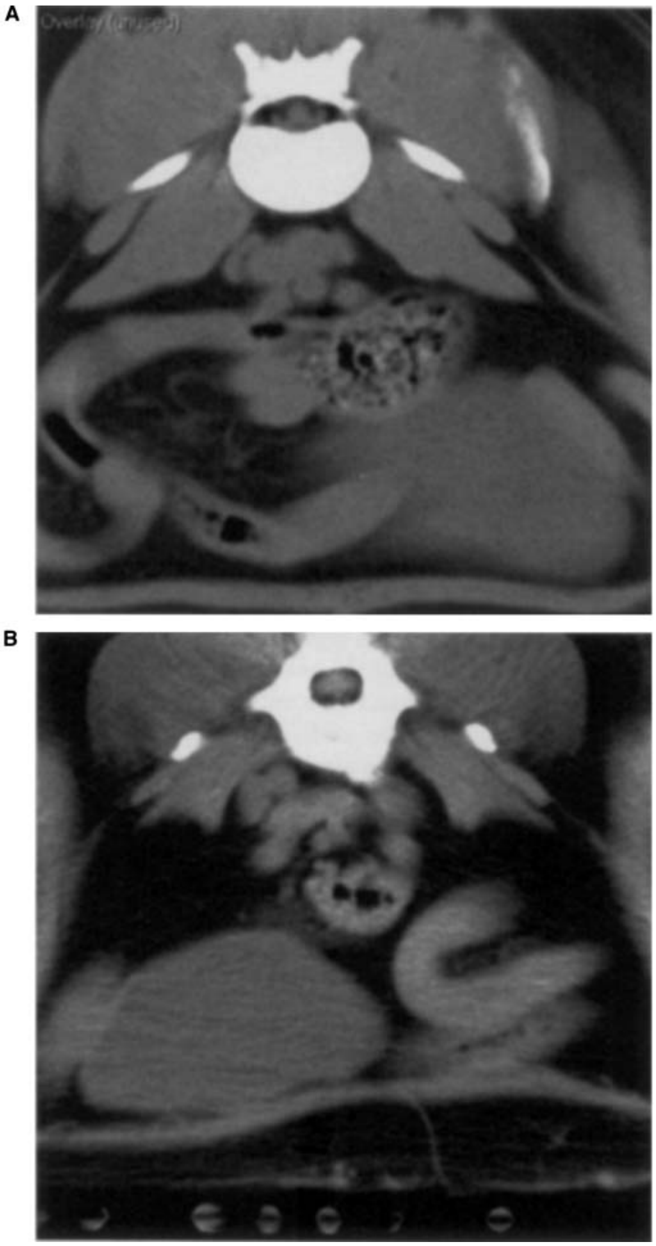

FIG. 4. Precontrast transverse CT images with obscuration of the ureter as a result of inadequate spatial resolution. (a) Obscuration at the level of the aortic bifurcation. (b) Obscuration by the empty colon. The right side of the dog is on the left of the image.

FIG. 5. Precontrast transverse images of the caudal abdomen. The ureters are visible as they course past the colon. The presence of an empty (a) or full (b) colon had no affect on the visualization of the ureters (arrows). C = colon; U = uterine stump; UB = urinary bladder. The right side of the dog is on the left of the image.

der wall (Fig. 1). Contrast medium within this hook was seen in all ureters on at least one of the three scans, and the apex of this curve was used to measure the distance between ureterovesicular junctions. On 10/12 ureters (83%), the entrance of the ureters into the bladder could be seen definitively on the first scan. On the remaining two, it was seen on the second scan. The dorsomedially directed portion was clearly seen on all ureters on one of the three scans; however, it could not be definitively localized on all scans. This junction was seen to occur over a sagittal length of 0.3–0.9 cm (1–3 slices). A jet of urine from the ureteral papilla could be detected at 8 of the 12 internal ureteral orifices (67%) at some point during scanning (Fig. 6). Distribution of contrast medium within the urinary bladder was variable, from a uniform ventral pool to various amorphous distributions (Fig. 6).

Measurements of bladder morphology are listed in Table 1. Bladder volume/kg body weight was variable and ranged from 1.78 to 17.67 mL/kg as no attempt was made to standardize bladder volume (dogs were given the opportunity to

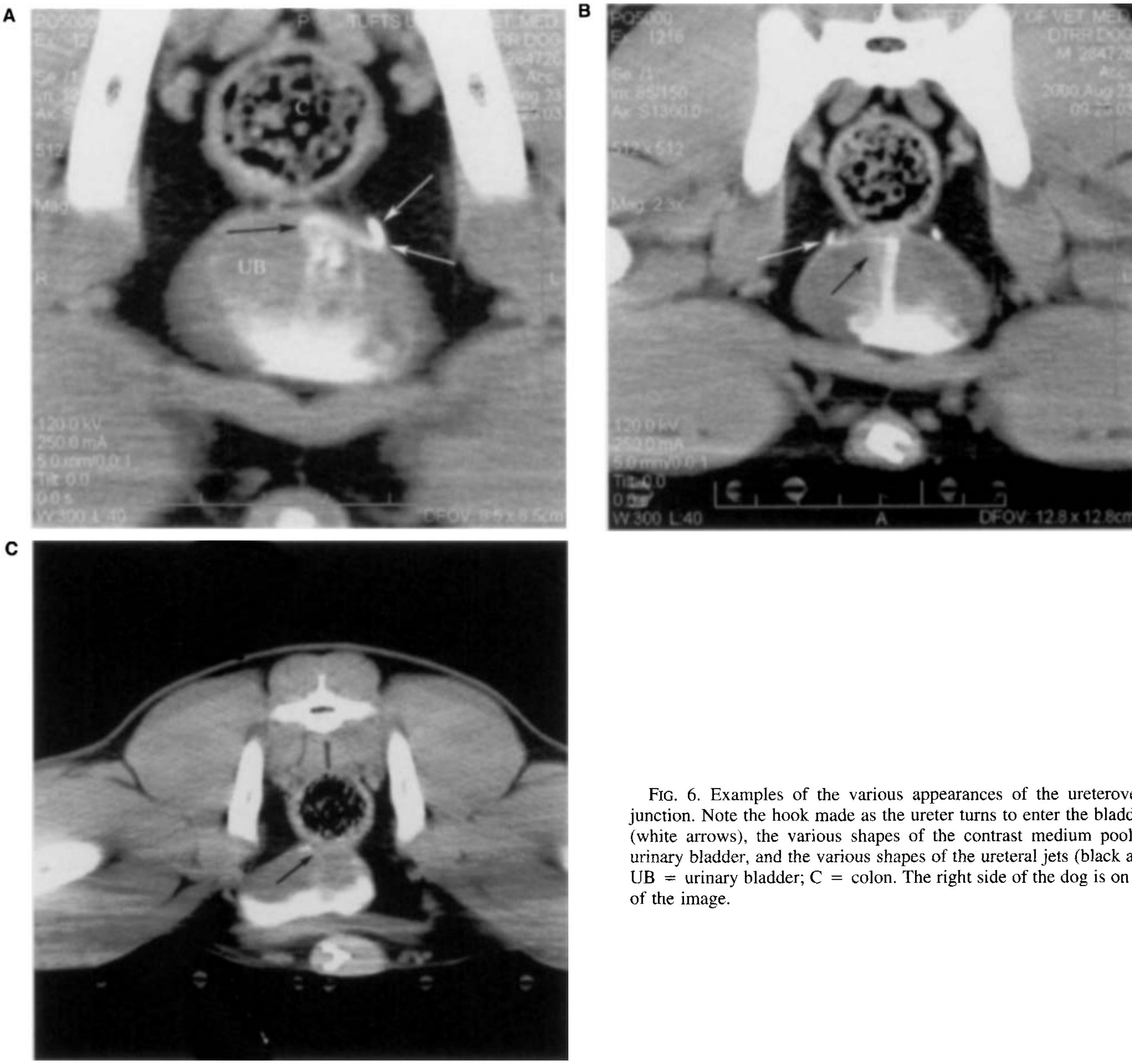

FIG. 6. Examples of the various appearances of the ureterovesicular junction. Note the hook made as the ureter turns to enter the bladder wall (white arrows), the various shapes of the contrast medium pool in the urinary bladder, and the various shapes of the ureteral jets (black arrows). UB = urinary bladder; C = colon. The right side of the dog is on the left of the image.

urinate, but catheterization to empty the bladders was not performed). Inter-ureterovesicular junction distance ranged from 1.96 cm to 4.01 cm (mean = 2.88 cm, standard deviation = 0.67). There was positive correlation between bladder volume and the distance between the ureterovesicular junctions (r^2 = 0.75, $p < 0.05$). The right and left ureterovesicular junctions were not seen at the same table position in all dogs. The left junction was caudal to the right on four of six scans (66%), by up to 1.5 cm. The caudal of the two ureteral entrances was distinctly identified on all studies and ranged from 1.8 to 3.9 cm cranial to the defined beginning of the urethra. There was no correlation between distance from the ureterovesicular junction to the beginning of the urethra and bladder volume (r^2 = 0.03, p = 0.6).

Fecal matter was seen in the colon on five of the six scans. The colon did not impinge on the bladder at the level of the trigone in the pre- or postcontrast studies. A tubular soft tissue structure was seen in the neutered female dogs between the caudal bladder and colon, believed to represent the uterine stump (Fig. 5a). This structure did not interfere with visualization of the ureters or trigone.

The beginning of the urethra was seen from 0.9 cm caudal to 1.2 cm cranial to the level of the cranial aspect of the pubic symphysis. There was a weak but statistically significant positive correlation between the distance from the beginning of the urethra to the pubis and bladder volume (r^2 = 0.35, p = 0.04).

On the postcatheterization scans, gas was detected in the

TABLE 1. Bladder Morphology in Normal Dogs Undergoing CT Excretory Urography

		Bladder Volume/Body Weight (mL/kg)	Inter-UVJ Distance (cm)	Distance from UVJ to Internal Urethral Orifice (cm)	Bladder Height/Width at UVJ (cm)	Distance from IUO to Pelvis (cm)
Precontrast	Mean	5.58	2.79	2.45	2.45/5.24	*
	SD	5.9	0.87	0.77	0.61/2.08	*
	Range	1.78–17.1	1.96–4.01	1.8–3.9	1.72–3.44/3.15–8.87	−0.6 to 0.9
Postcontrast	Mean	6.76	2.94	2.55	2.69/5.42	*
	SD	5.53	0.52	0.68	0.40/1.91	*
	Range	2.91–17.6	2.48–3.75	2.1–3.9	2.33–3.41/3.78–8.84	−0.9 to 1.2

Mean values (mean), standard deviation (SD), and ranges given for all categories except the distance from the internal urethral orifice to the pelvis (negative value indicates the urethral orifice is caudal to the pubis while positive values are cranial to pubis).
UVJ, ureterovesicular junction; IUO, internal urethral orifice.

bladder of two dogs. The balloon did not prevent visualization of the ureteral entrances, however only 1 of 12 possible ureteral jets was detected (Fig. 7a) on these scans. The location of the caudal aspect of the balloon correlated with the level of the internal urethral orifice as determined on the precatheterization scans in only one study, but was 3 mm to 18 mm cranial to the level of the urethra on four other studies indicating that the cuff had moved away from the bladder neck. The balloon obscured the identification of the internal urethral orifice completely in one study. Contrast medium was seen in the catheter, urethra, and vagina on the postcatheterization scans (Fig. 7b).

Average total scan time was 72 min. Significant delays during scanning were encountered because of X-ray tube heat load. The shortest scan time was 55 min.

Discussion

Ureteral disease and dysfunction have long been diagnostic challenges to the veterinarian, and current methods of visualizing the ureters all have their drawbacks. The normal ureter cannot be visualized radiographically. It is only visible when markedly distended or filled with contrast medium. Excretory urography has been the imaging modality of choice in evaluation of the ureter. However, superimposition of structures (intestinal contents, masses, abdominal effusion, retroperitoneal effusion, skeletal structures) can prevent visualization of the ureter. This is especially relevant in the diagnosis of ureteral ectopia, where superimposition of surrounding structures can greatly confuse interpretation. Renal excretion or concentration impairment (due to renal insufficiency/failure or chronic ureteral obstruction) can limit the amount or concentration of contrast medium in the ureter, hampering visualization. Ultrasonography has also been used to evaluate the ureter.[18–20] Because of its small diameter, however, a ureter of normal diameter cannot be visualized ultrasonographically. Interposition of gas or intestinal structures can also prevent visualization of the ureter with this modality.

There are many potential benefits of CT excretory urography over the standard modalities of ureteral imaging. Lack of superimposition allows improved visualization of the ureter and ureterovesicular junction both with and without contrast medium administration. The ability to perform two-dimensional multiplanar and three-dimensional graphical reconstructions of the ureter and ureterovesicular junction facilitates diagnosis and surgical planning of ureteral diseases. The ability of CT to detect lower concentrations of contrast medium in the ureter has two benefits: It lowers the dose of contrast medium required for an adequate study and it allows visualization of the ureters in the face of lower volume or concentration of excreted contrast medium in patients with renal disease. Scans focusing on the areas of interest should allow for shorter overall procedure time compared to the multiple positional radiographs required for EU. Our long scan times reflect our inexperience and the large amount of data acquired. With experience and focused studies, scan times and X-ray tube load should be significantly decreased.

In this study, we found that the ureter was easily identified and the anatomy easily evaluated on both precontrast and postcontrast scans. Measurements of the ureteral diameter were smaller than published anatomic measurements.[21] The overall ureteral diameter remained smaller than published measurements on postcontrast images, although the overall postcontrast diameters were slightly larger than those in the precontrast images. This was believed to be caused by ureteral enlargement secondary to osmotic diuresis by the contrast medium causing increased excreted volume, and/or the CT blooming artifact.

The morphology of the ureterovesicular junction was easily evaluated. On the precontrast studies, the ureterovesicular junction was visualized as an abrupt confluence of the ureter with the bladder, and often the "hook" could be appreciated. The distinct hook of the ureter as it turned to enter the bladder wall was seen in all postcontrast studies. Although the two ureterovesicular junctions were not at the same level in most dogs, the caudal of the ureterovesicular junctions was well cranial to the internal urethral orifice in

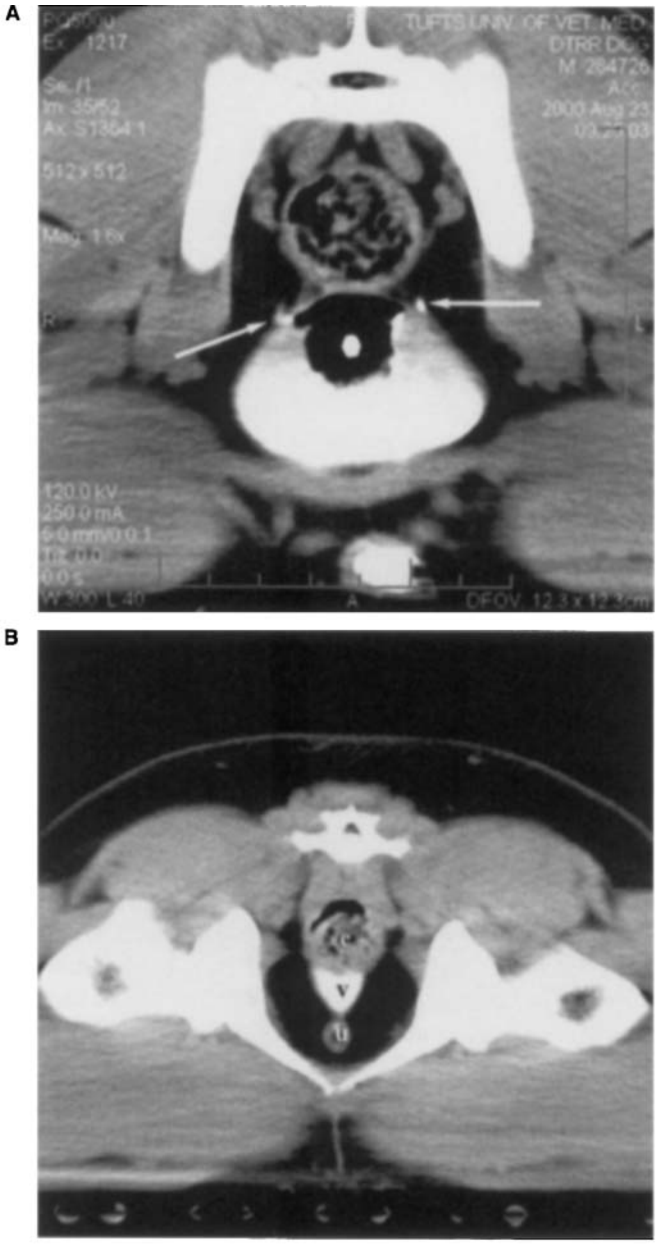

Fig. 7. Appearance of artifacts associated with catheterization. (a) The bladder neck with balloon catheter in place and inflated. The hook of the ureter's entrance into the bladder can still be identified, however the region is obscured. Note the gas within the bladder dorsal to the balloon and contrast medium in the penile urethra. (b) Contrast medium introduced into the vagina (v) which could mimic uretero-vaginal ectopia. (c = colon, u = urethra with catheter). The right side of the dog is on the left of the image.

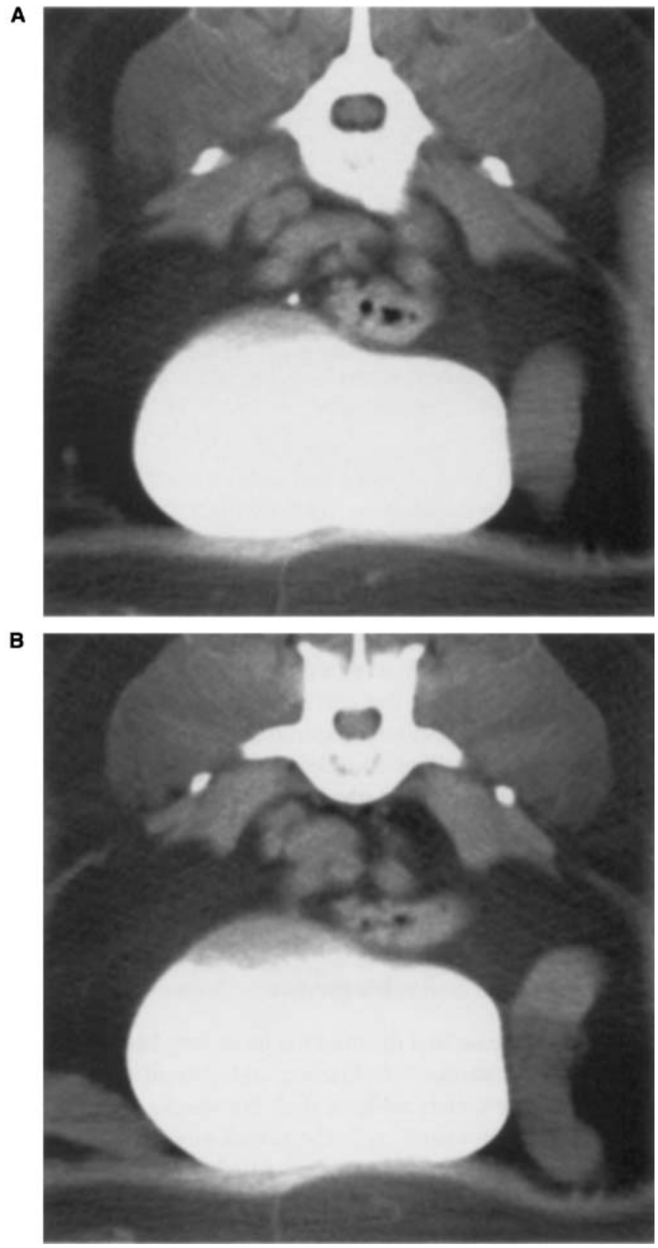

Fig. 8. (a) Loss of visualization of the left ureter as a result of peristalsis excluding contrast medium from the lumen, and inadequate spatial resolution. (b) Both ureters are obscured as a result of peristalsis. The right side of the dog is on the left of the image.

all dogs. Tapering of the bladder neck was seen between the ureterovesicular junctions and internal urethral orifice in all dogs, regardless of the degree of bladder distension. Although bladder distension affected the inter-ureterovesicular junction distance, it did not affect the visibility of the ureterovesicular junction or the distinct tapering of the bladder between the ureterovesicular junction and the internal urethral orifice. It appears from these results that standardization of bladder volume may not be necessary when assessing the location of the ureterovesicular junction relative to the internal urethral orifice in patients with suspected ureteral ectopia. The distance from the internal urethral orifice to the public symphysis was widely variable between dogs and in individuals over time due to bladder filling, and therefore cannot be recommended as a reliable landmark for identification of the internal urethral orifice.

Potential pitfalls in interpretation of clinical studies were encountered in our study and included loss of visualization of the ureter on precontrast images, peristalsis excluding contrast medium from the ureter, and artifacts associated with catheterization.

In places, accurate localization and measurement of the ureter on precontrast images was not possible because of obscuration of the ureter by closely associated structures, such as the abdominal great vessels and occasionally the colon (Fig. 4). In the latter instance, the ureter could usually be seen adjacent to the colonic wall. However, as the result of inadequate spatial resolution, the medial margin could not be identified for measurement. Complete obscuration of the ureter occurred consistently in the region of the aortic bifurcation.

Peristaltic contractions resulted in intermittent and inconsistent disappearance of contrast medium within the ureter (Fig. 8). If this occurred in an area where the ureter was immediately adjacent to surrounding structures (such as the colon or aortic bifurcation), then the post contrast ureter may be completely obscured, as on the precontrast images. However, contrast medium was seen in the ureter at all measured points during at least one of the three postcontrast scans. This implies that if visualization of contrast medium within the ureter at a specific point is necessary (e.g., the ureterovesicular junction in instances of suspected ureteral ectopia), then multiple scans of the region of interest may be necessary. However, repeated scanning of the entire urinary tract may not be necessary, limiting the study only to the area of interest.

Catheterization was not necessary in identification of the internal urethral orifice. It more often confused interpretation because of artifacts associated with placement (contrast medium introduced into the vagina, contrast medium within the urethra and catheter lumen, balloon slipping forward into the bladder, gas introduced into the bladder) and gas within the balloon (Fig. 7).

In conclusion, we found that CT excretory urography using a simple protocol with minimal patient preparation was sufficient to evaluate the ureter and the ureterovesicular junction. The ureters are adequately identified and measured on both pre- and postcontrast scans, and the entrance of the ureters into the bladder neck can be distinctly identified. However, because of peristalsis, the ureterovesicular junction may need to be scanned multiple times to visualize contrast medium in the ureterovesicular junction, and thereby distinctly identify the entrance of the ureter into the bladder. Because the ureterovesicular junction to internal urethral orifice distance did not appear to be affected by bladder volume, standardization of bladder volume is not likely to be needed for evaluating ureteral ectopia.

The protocol used in this study, while thorough, may result in unnecessarily high patient dose and X-ray tube heat load to be useful in clinical practice. Because of this, reducing the area scanned to the area of interest is recommended. Using the herein described slice thickness, index and field of view parameters, the scan can be limited to the ureterovesicular junction and urethra in cases of suspected ureteral ectopia to reduce patient dose and scan time. Since submission of this manuscript, the authors have successfully used this limited scan technique to successfully diagnose ureteral ectopia and to localize ureteral rupture.

We feel that this preliminary study of normal anatomy will facilitate the clinical use of CT in the evaluation of the diseased ureter.

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