Computed tomography urography 2: clinical applications

Contrast-enhanced computed tomography urography has become possible because of the development of multidetector technology, which has evolved to try and increase its diagnostic efficacy and reduce the radiation exposure. This review outlines the applications of computed tomography urography in day-to-day urology practice.

Computed tomography has become the cornerstone of medical practice and this is no less evident in urology. Computed tomography urography is very useful in diagnosing congenital abnormalities, urinary tract trauma, benign and malignant conditions. However it has diagnostic problems which can be technical, reporting normal anatomical structures and variants as pathology, benign filling defects and wall thickening interpreted as malignant change. Traditional computed tomography urography is done in three phases, unenhanced, nephrogenic and excretory. Many protocols have been published combining the various phases or reducing the computed tomography parameters in an effort to reduce radiation dose while still maintaining the diagnostic quality of images. This second part of a two-part review looks at how computed tomography urography is applied clinically.

Congenital abnormalities and anatomical variants

Congenital abnormalities and anatomical variants (renal agenesis, ureteral duplication, renal ectopy and horseshoe kidneys) can be diagnosed easily by computed tomography urography. Pelvi-ureteric junction obstructions are normally diagnosed in mid adulthood. This is achieved using a triple-bolus computed tomography urography technique to determine if these obstructions have extrinsic causes, one of the commonest being aberrant renal artery (Mitsumori et al, 2000). To obtain images of the renal vessels computed tomography angiography is traditionally performed, but if a triple-bolus computed tomography urography is performed it clearly identifies the renal vessels, renal parenchyma and urinary tract. This highlights the importance of computed tomography urography in reducing the radiation dose to the patient and also getting enhanced and meaningful imaging of the urinary tract.

Ureteroceles (single system or duplex) can also be detected by computed tomography urography and appear as a filling defect in the bladder near the ureteral insertion (Dillman et al, 2007).

Trauma

Urinary tract trauma is traditionally divided into trauma to the upper and lower urinary tract. Upper urinary tract trauma includes injuries kidneys and ureters. The incidence of major renal injury caused by blunt or penetrating abdominal trauma is 8–10% (Wah and Spencer, 2001). Renal injuries were clinically classified by the Organ Injury Scaling Committee of the American Association of the Surgery of Trauma (AAST) and Federle described an easy and intuitive imaging classification of renal trauma based on computed tomography findings (Federle, 1990; Santucci et al, 2001; Sutton, 2002a,b). *Table 1* compares the two classifications.

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Table 1. Federle classification and American Association of the Surgery of Trauma (AAST) classification of renal trauma

Federle imaging classification		AAST classification	
Category	Injury	Grade	Injury
I	Minor – contusion, cortical laceration not extending into calyx	1	Contusion and/or subscapular haematoma
II	Major – cortical laceration extending into collecting system	2	Cortical laceration less than 1cm not extending into calyx
III	Catastrophic – renal pedicle injury, shattered kidney	3	Cortical laceration more than 1cm extending into calyx
IV	Pelviureteric junction injury	4	Cortical laceration extending to corticomedullary junction or collecting system, renal vessel injury with contained haemorrhage
		5	Renal pedicle avulsion or shattered kidney

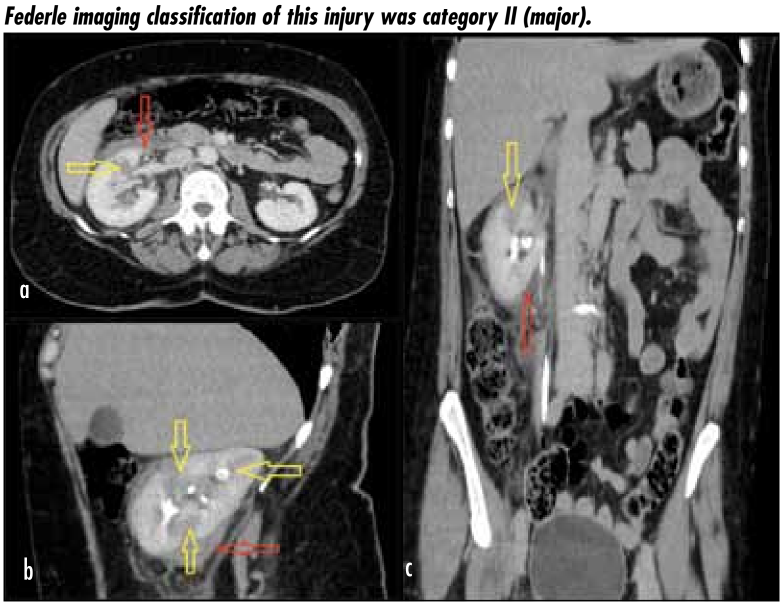
From Sutton (2002b)

The most common indications for imaging the kidneys after blunt abdominal trauma are visible haematuria or non-visible haematuria plus signs of renal damage, in particular shock (systolic blood pressure ≤90 mmHg) or significant other associated injuries. Category I or AAST grade 1 renal injuries account for 75–98% and require conservative management only. The majority of category II and AAST grade 2 renal injuries, such as that illustrated in *Figure 1*, can be managed non-surgically (Cheng et al, 1994). Late onset hypertension has been reported in patients with category II renal injuries managed conservatively (Cass et al, 1987). Category III/IV and AAST grade 3/4 patients usually require surgical intervention particularly when there are signs of vascular compromise when conservative management is inappropriate. AAST grade 5 injuries require immediate surgery to salvage the kidney (Sutton, 2002b).

Ureteric injuries are more common in penetrating trauma and normally affect the mid to lower ureter. Blunt trauma in children as a result of rapid deceleration injuries may avulse the ureteropelvic junction (Reznichek et al, 1973).

Lower urinary tract injuries involve the bladder and urethra. Rupture of the bladder is usually associated with pelvic fractures and very rarely spontaneously (associated with pre-existing bladder wall abnormality or excessive straining). Blunt trauma is the most common mechanism of injury. Iatrogenic bladder rupture can be seen following pelvic surgery or bladder instrumentation. Bladder rupture can be extra- or intraperitoneal depending on whether the peritoneal covering of the bladder has been breached or not. Computed tomography urography is used to evaluate the extent of bladder trauma using intravenous and retrograde contrast media delivery. Adequate filling of the bladder is essential for an optimal study.

Figure 1. Computed tomography images of trauma to the right kidney with (a) axial, (b) sagittal and (c) coronal reformatting. The patient had been involved in a road traffic accident and suffered lacerations to the right kidney with perinephric haematoma. The lacerations are marked with yellow arrows and haematoma with red arrows. The Federle imaging classification of this injury was category II (major).



Evaluation of benign urinary tract pathologies

Renal cysts

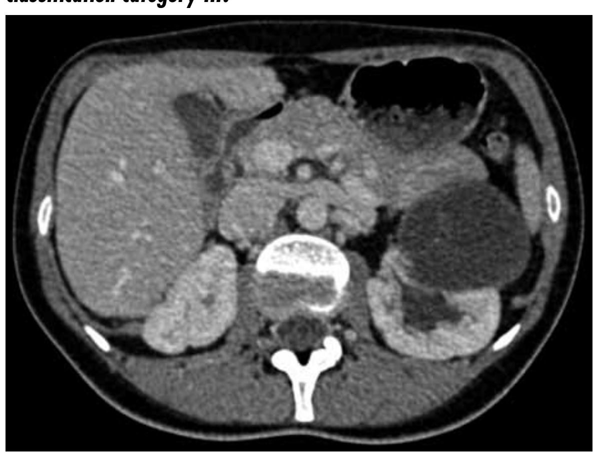
In his autopsy study, Kissane (1976) showed that more than 50% of patients aged 50 years or above will have at least one or more simple renal cysts. Subsequently in 1986 Bosniak developed a classification system for renal cysts using findings on computed tomography scan. *Figures 2* and *3* show two renal cysts classified using the Bosniak classification. This classification (*Table 2*) enables appropriate assessment and follow-up of renal cysts (Israel and Bosniak, 2005). In some cases magnetic resonance imaging follow-up may also be required as this provides greater information on complex cyst structures.

Renal and ureteric calculi

Nephrolithiasis and urolithiasis affect 2% of the UK population at any one time with an overall lifetime incidence of 15% (Mooney, 2007). Of calculi 90% are radio-opaque (calcium-containing calculi) on plain X-ray with the remaining 10% being radiolucent (e.g. urate and

Figure 2. A simple renal cyst in the right kidney. Bosniak classification category I.

Figure 3. A complex renal cyst in the left kidney. Bosniak classification category IIF.



cysteine calculi) (Sutton, 2002b). Both radiolucent and radio-opaque calculi on plain film can be detected by unenhanced computed tomography urography, but there are some exceptions such as stones caused by indinavir and atazanavir which are undetectable (unless present with some calcium oxalate or calcium phosphate deposition) (Sutton, 2002b). *Figure 4* shows an unenhanced computed tomography scan of a radio-opaque ureteric calculus. Intravenous urogram is unable to detect calculi in up to 48% of cases (Fielding et al, 1997). Ultrasound has also been used to locate stones but it does not identify stones within the ureter (Sutton, 2002b). Because of this disadvantage ultrasound is not the investigation of first choice in adults but is strongly recommended in children and pregnant women to avoid radiation (Smith et al, 2000). Unenhanced computed tomography urography is the current gold standard for detection of calculi with a sensitivity of 94% and specificity of 97%, with only 52% and 94% for intravenous urogram, and ultrasound much poorer at 19% and 97% respectively (Sutton, 2002b).

Any calculi found in the renal tract are generally removed urgently, but some calculi are difficult to extract and can lead to complications. These complications include urinary tract obstruction, haemorrhage, perforation and infections such as xanthogranulomatous pyelonephritis which is associated with calculi in 76% of cases (as seen in *Figure 5*) (Kim, 2001; Craig et al, 2008).

Renal papillary necrosis

These are detected on computed tomography urography as renal papilla hypoenhancement suggesting impaired perfusion, abnormal contrast-filled cavities within the medulla and abnormal contrast-filled material extending peripherally from the calyces (Lang et al, 2004; Dillman et al, 2007).

Medullary sponge kidney

Medullary sponge kidney is a cystic renal disease which leads to dilation of the collecting ducts and cyst formation. The radiological appearances are of abnormal linear

Figure 4. Unenhanced computed tomography scan showing a large (12 mm) obstructing proximal left ureteric calculus and moderate left hydronephrosis.

Table 2. Bosniak classification of renal cystic disease

Category I (malignant risk less than 1%)	A benign simple cyst with a hairline thin wall that does not contain septa, calcifications or solid components
	It measures water density and does not enhance
	No follow-up required
Category II (malignant risk less than 3%)	A benign cyst that may contain a few hairline thin septa in which 'perceived' enhancement may be present
	Fine calcification or a short segment of slightly thickened calcification may be present in the wall or septa
	Uniformly high attenuation lesions <3 cm (so-called high-density cysts) that are well marginated and do not enhance are included in this group
	No follow-up required
Category IIF (malignant risk 5–10%)	Cysts that may contain multiple hairline thin septa or minimal smooth thickening of their wall or septa
	Perceived enhancement of their septa or wall may be present
	Their wall or septa may contain calcification that may be thick and nodular, but no measurable contrast enhancement is present
	These lesions are generally well marginated
	Totally intrarenal non-enhancing high-attenuation renal lesions >3 cm are also included in this category
	These lesions require follow-up imaging studies to prove benignity
Category III (malignant risk 40–60%)	'Indeterminate' cystic masses that have thickened irregular or smooth walls or septa in which measurable enhancement is present
	These are surgical lesions, although some will prove to be benign (e.g. haemorrhagic cysts, chronic infected cysts and multiloculated cystic nephroma), some will be malignant (e.g. cystic renal cell carcinoma and multiloculated cystic renal cell carcinoma)
	Surgical excision recommended
Category IV (malignant risk >80%)	These are clearly malignant cystic masses that can have all the criteria of category III, but also contain enhancing soft tissue components adjacent to, but independent of, the wall or septum
	These lesions include cystic carcinomas and require surgical removal

From Israel and Bosniak (2005)

collections of contrast material within the renal medulla as if they have been brushed onto the image (Caoili et al, 2002). Also present on computed tomography images is papillary calcification as seen in *Figure 6*.

Ureteritis cystica

This is a benign chronic inflammatory condition affecting the urinary tract and involving the ureter, caused by chronic infection or ureteric stones. Computed tomography urography demonstrates numerous tiny filling defects at the proximal ureter. These can be mistaken for urothelial neoplasia (Dillman et al, 2007).

Urothelial papillomas

These can be seen as filling defects in computed tomography urography and can become quite large, making them indistinguishable from malignancy (Dillman et al, 2007).

Urinary tract infections

Computed tomography urography is the investigation of choice for infections such as unresolved acute pyelonephritis (not responding after 72 hours of treatment), emphysematous pyelonephritis, renal abscess, perinephric abscess, pyonephrosis and chronic inflammatory conditions such as xanthogranulomatous pyelonephritis, tuberculosis and chronic pyelonephritis (Sutton, 2002b). A characteristic finding of acute pyelonephritis is 'discrete rays of alternating attenuation that extends to the capsule' during the nephrographic phase of an enhanced computed tomography urography. Acute infection may also show as 'one or more hypodense areas within the renal parenchyma with some obliteration of the corticomedullary junction'. Renal parenchymal abnormalities are seen best during the nephrogenic phase. Persistent contrast enhancement of a delayed computed tomography indicates the presence of an inflammatory mass instead of a tumour. The unenhanced phase allows identification of complications of infection such as gas (*Figure 7*), calculi, haemorrhage and renal parenchymal calcifications (Akbar et al, 2004).

Figure 5. Contrast-enhanced computed tomography scan demonstrating bilateral staghorn calculi with xanthogranulomatous pyelonephritis. There is distension of the right collecting system secondary to inflammatory debris.

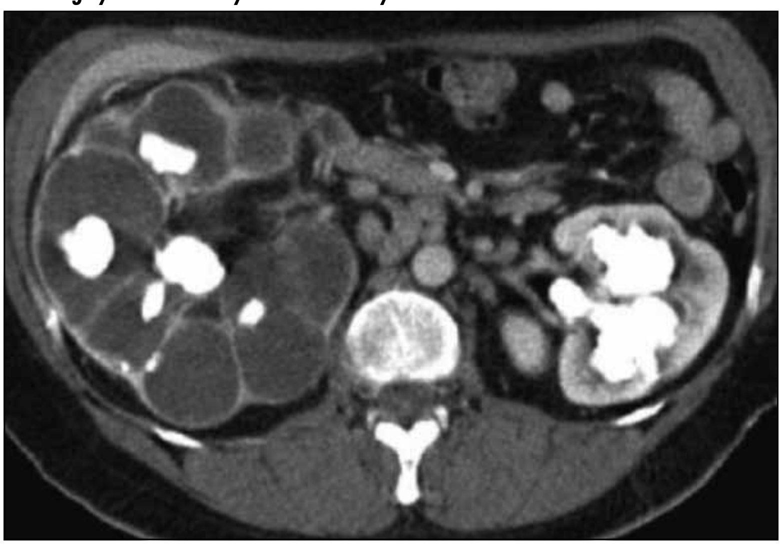
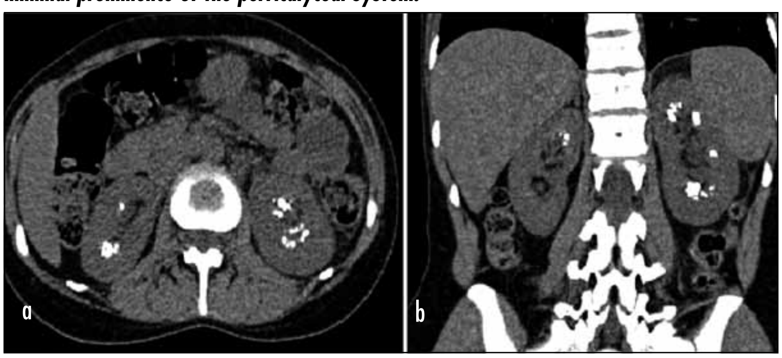


Figure 6. a. Axial and (b) coronal computed tomography images of a patient with known medullary sponge kidneys. There is evidence of multiple stones in both kidneys with minimal prominence of the pelvicalyceal system.



Angiomyolipoma

Angiomyolipomas are the most common benign tumour of the renal parenchyma. They are composed of adipose tissue, blood vessels and muscle cells. Although the majority of cases (80%) are sporadic, there is a strong link in the remaining 20% to neurocutaneous disorders such as tuberous sclerosis (Lowe et al, 2000). Angiomyolipoma can present as an incidental finding on computed tomography (*Figure 8*), but it usually presents with spontaneous retroperitoneal haemorrhage and shock (*Figure 9*) (Moratalla, 2009). Computed tomography findings of macroscopic fat are generally diagnostic as illustrated in *Figure 8*.

Malignant urinary tract conditions

Computed tomography urography not only plays an important role in providing a diagnosis of malignant

Figure 7. A patient who was treated for acute pyelonephritis, which did not respond well to antibiotic therapy. Subsequent computed tomography showed a left renal abscess that contained a few tiny gas bubbles. This was drained under computed tomography guidance.

tumours but is essential for further staging, planning of surgery or radiotherapy if subsequently required.

Renal call carcinoma accounts for 85% of adult renal cancer and 3% of all adult neoplasms (*Figure 10*). Half of these are discovered incidentally as a result of abdominal imaging performed for non-urological purposes or as a result of haematuria, hence are small and at an early stage (Sheth et al, 2001). The increased vascularity of conventional renal call carcinoma as a result of overexpression of growth factors involved in angiogenesis such as vascular endothelial growth factor and platelet-derived growth factor produces strong enhancement of the tumours on corticomedullary-phase computed tomography images (in excess of 100 HU from unenhanced to contrast-enhanced images). Unfortunately, if the lesion is small or located within the cortex, it may be difficult to identify against the background of normal cortical enhancement. Calcification is visible in a third of renal cell carcinomas (*Figure 11*) (Sutton, 2002b).

Transitional cell carcinomas of the renal pelvis and ureter are less common than renal call carcinomas and usually present with haematuria. Computed tomography urography can identify tumours from 0.5 cm diameter and upwards. Tumours appear as ill-defined, hypodense (8–30 HU) lesions in relation to normal renal tissue (30 HU) with a slightly increased density than urine. They do not enhance well with contrast because they have poor vascularity (*Figure 12*). Focal circumferential urothelial wall thickening on computed tomography urography has more than 50% chance of being a transitional cell carcinoma (Caoili et al, 2005). *Figure 13* shows a transitional cell carcinoma in the bladder.

Figure 8. Computed tomography scan showing an incidental low density area in the inferior pole of the left kidney with fat density measuring 20 mm in size and in keeping with angiomyolipoma.

Figure 9. Patient presented with hypovolaemic shock and computed tomography confirmed a large angiomyolipoma occupying the lower pole of the right kidney measuring approximately 11.5 cm x 8 cm in size (yellow arrow). The angiomyolipoma is surrounded by retroperitoneal haematoma consistent with rupture. Within the angiomyolipoma there are areas of high density suggestive of a combination of areas of bleeding as well as aneurysm formation within the small abnormal vessels inside the tumour.

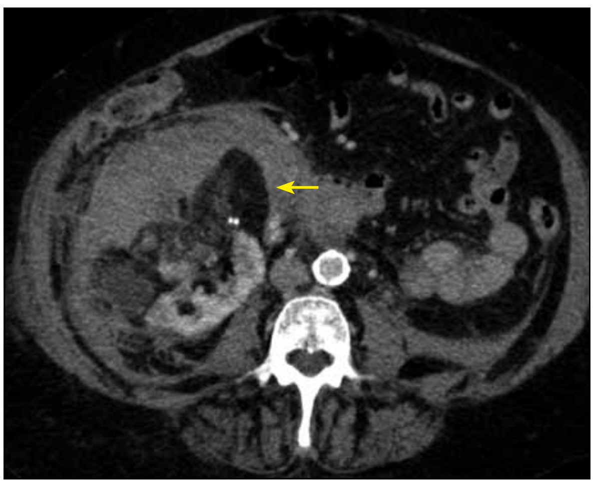


Figure 10. A renal cell carcinoma mass in the right kidney. a. Axial slice and (b) coronal reconstruction of the data set.

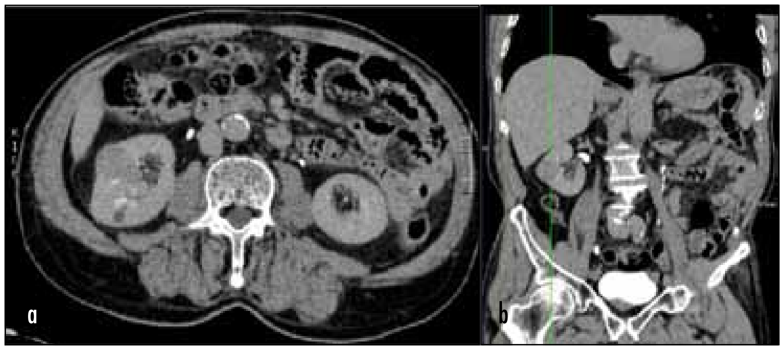
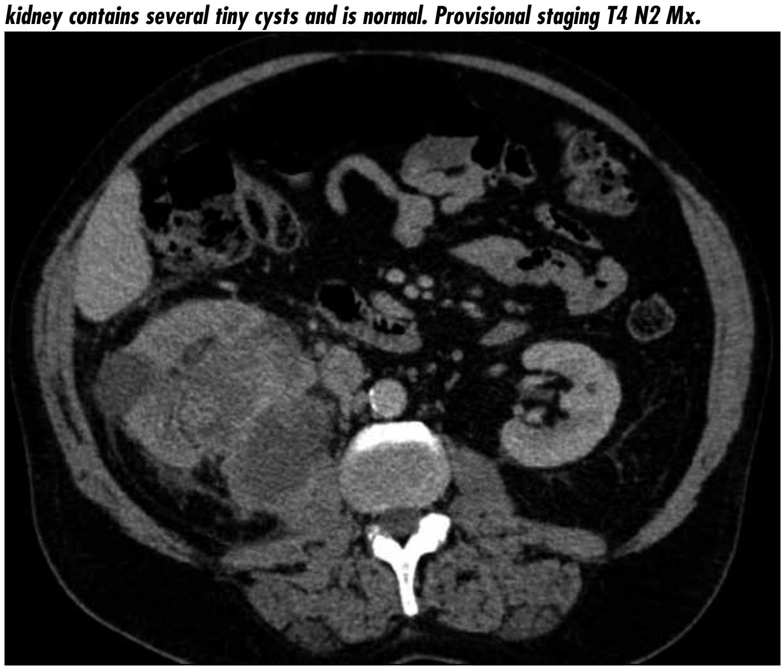


Figure 11. A large renal cell carcinoma in the right kidney. There is invasion of the adjacent right psoas muscle. A simple cyst is present in the lower pole of this kidney. The lower pole collecting system, ureter and bladder contains fluid of increased density consistent with blood and there are a few slightly enlarged paraaortic nodes. The left kidney contains several tiny cysts and is normal. Provisional staging T4 N2 Mx.



Conclusions

In many institutions worldwide computed tomography urography has replaced intravenous urography especially in the evaluation of patients with haematuria. Although computed tomography urography has become the 'gold standard' in the investigation of most urinary tract pathologies, there is always concern about exposing the patient to a high radiation dose, especially in the young. Computed tomography urography has developed considerably over the last decade and the future lies in the reduction of radiation dose through low dose imaging protocols while maintaining image quality through advancement in technology. **BJHM**

Figure 12. A right renal pelvis transitional cell carcinoma which during the excretory phase shows reduced enhancement compared to adjacent renal tissue.

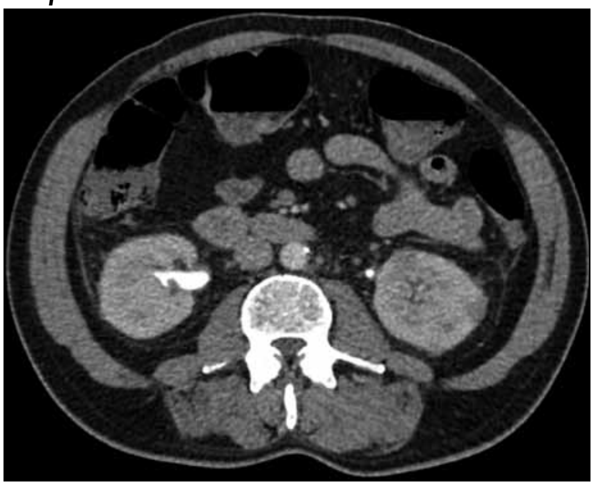


Figure 13. An irregular mass lesion in the right side of the bladder close to the vesicoureteric junction consistent with a bladder tumour.

KEY POINTS

- Computed tomography urography has become a key part of the management of urinary tract pathology.
- It is able to give important clinical information in the setting of trauma, benign and malignant lesions.
- Different pathologies require tailored imaging protocols and techniques which are based on the urologist's clinical suspicions.

Figure 5 *is reproduced from Craig et al (2008) by kind permission of the Radiological Society of North America.*

Conflict of interest: none.

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