Computed tomography urography 1: techniques and technology

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 highlights important aspects of computed tomography urography as an imaging technique.

Sir Godfrey Hounsfield developed the first commercially available computed tomography scanner which, on 1 October 1971, was used at Atkinson Morley's Hospital, London to scan a cerebral cyst (Berrington de González et al, 2009). As a result of his great contribution to computed tomography scans, the name of Sir Godfrey Hounsfield will always be remembered as a measure of radiodensity.

The computed tomography urography working group of the European Society of Urogenital Radiology computed tomography defined urography as:

> **'a diagnostic examination optimized for imaging the kidneys, ureters and bladder. The examination involves the use of multidetector CT [computed tomography] with thin-slice imaging, intravenous administration of a contrast medium, and imaging in the excretory phase' (Van Der Molen et al, 2008).**

Advances in computed tomography software technology provide clinicians with effective three-dimensional volume rendering and display of images in various planes. This has greatly improved anatomical accuracy and supports comprehensive radiological diagnosis (Kim and Cho, 2003). Various centres have described different computed tomography urography techniques but the main objective of the investigation is to maximally distend and completely opacify the urinary tract with contrast material to improve abnormality detection (Dillman et al, 2007). The radiation dose in computed tomography urography is high and therefore different protocols have been applied to reduce the dose by tailoring it to age and specific conditions using the ALARA (as low as reasonably achievable) principle (Van Der Molen et al, 2008). This is part one of a two-part review looking at how computed tomography urography has and will continue to shape modern urological practice.

Techniques of computed tomography urography

The majority of computed tomography urography techniques require little or no patient preparation. The use of oral contrast medium such as diatrizoic acid (3,5-diacetamido-2,4,6-triiodobenzoic acid) or barium sulphate suspension for bowel visualization should be avoided as it interferes with the computed tomography urography images (Nolte-Ernsting and Cowan, 2006; Van Der Molen et al, 2008). Fluids (oral or intravenous) can be used to promote diuresis and act as a negative contrast medium for the bowel (Van Der Molen et al, 2008). They may also help to delineate the ureteric segments as there are fewer beam-hardening artefacts (Nolte-Ernsting et al, 2001; Kawamoto et al, 2006). Water (maximum 1 litre) or intravenous infusion of 0.9% saline (maximum 500 ml) can be given 20–60 minutes before computed tomography imaging.

The patient typically lies in the supine position for illustration of the urinary tract. However, Morcos (2007) showed that turning the patient a few times before excretory phase imaging could help avoid the layering effects of intravenous contrast.

Traditionally there are three phases in computed tomography urography (*Figures 1a–c*), the unenhanced phase, nephrogenic phase and excretory phase.

Intravenous contrast media

The intravenous contrast most commonly used is a non-ionic iodinated monomer with chemical structure varying depending on the manufacturer. Different methods of administration are used to maximally distend and opacify the urinary tract. The three most commonly used are 'single-bolus', 'split-bolus' and recently the 'triple-bolus' (Caoili et al, 2002; Dillman et al, 2007).

Computed tomography urography is generally done using the single-bolus method, which is a tri-phasic technique first described in 1998 (McNicholas et al, 1998). The bolus contains 100–150 ml of non-ionic contrast media injected at 2–3 ml/s. The volume varies according to the patient's weight and the concentration of the contrast media. Initially an unenhanced computed tomography scan is taken followed by injection of the contrast medium. After approximately 100 seconds a nephrographic phase computed tomography image is obtained

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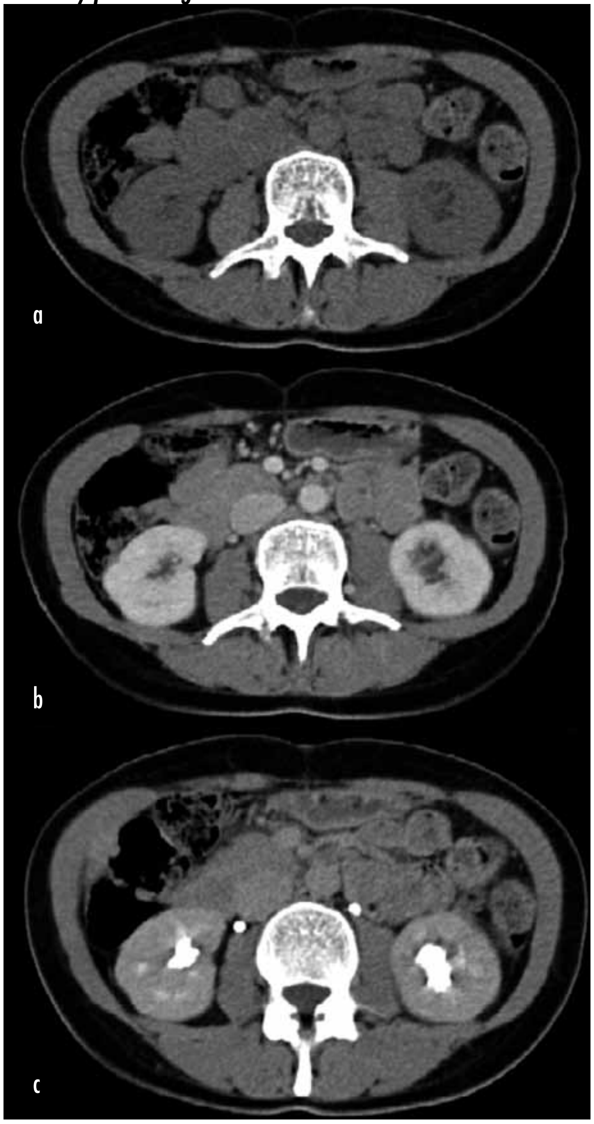
which allows visualization of the renal parenchyma, and 240–480 seconds later another computed tomography image is taken for the excretory phase which allows visualization of the upper urinary tract and the bladder. A higher dose of radiation is involved as a result of using three computed tomography scans.

The split-bolus technique was first described in 2001 and involves two injections of contrast media and two imaging phases (Chai et al, 2001; Chow and Sommer, 2001). The initial unenhanced phase computed tomography scan is followed by two boluses of contrast media with a time delay between each injection. The volume of contrast media is usually 50 ml per bolus at 2 ml/s, but the volume of each injection can be varied, i.e. one larger than the other, up to a maximum of 100 ml (varied according to body weight/concentration) can be done. The most recent work suggests a 600–660 second gap between injections (Turney et al, 2006; Cowan et al, 2007). After approximately 100 seconds, a computed tomography scan is taken which shows both nephrographic and excretory phases. This means that two phases can be done with one scan, reducing the radiation dose compared to the single-bolus technique.

The newer triple-bolus method was first described by Kekelidze and his group from the Netherlands in 2006. First an unenhanced phase computed tomography image is taken followed by three boluses of contrast media. The first bolus of 30 ml is followed 420 seconds later by a second bolus of 50 ml then after 20 seconds a third bolus of 65 ml is given. These are injected at 2–3 ml/s. The computed tomography scan is then done 70 seconds after the final bolus injection. This gives an arterial, nephrographic and an excretory phase in one scan, having the same advantage over single-bolus as split-bolus (less radiation) and also the added information of an arterial phase in case there is pathology in the renal arteries (Kekelidze et al, 2006).

Figure 1. The three phases of scanning in computed tomography urography as axial slices; (a) unenhanced, (b) nephrogenic and (c) excretory phase images.



Ancillary manoeuvres

An important part of computed tomography urography is the use of ancillary manoeuvres to aid the visualization of the urinary tract in the excretory phase image. The three manoeuvres used are compression bands, furosemide and hydration.

Compression bands

Compression bands have been used in conventional intravenous urography protocols and more recently in computed tomography urography. These external compression bands have shown some benefit in increasing opacification of the mid-distal ureter and distension of the upper urinary tract. However, similar effects were demonstrated when the timing of excretory phase images was delayed from 300 seconds to 450 seconds. Therefore the use of compression bands is currently less popular (Caoili et al, 2005).

Low dose furosemide

A low dose furosemide (5–10 mg) injection before the administration of intravenous contrast media improves opacification and urinary tract distension with homogenous distribution of contrast media as well as shortening of the time delay to the excretory phase. Sanyal et al (2007) found there was complete ureter opacification in 93% of cases.

Hydration

The use of intravenous saline for hydration has shown mixed results. It improves urinary tract distension and opacification as a result of forced diuresis. However, there have been reports of high attenuation values of excreted contrast media of 950–2550 Hounsfield units (HU) which limit assessment of the renal pelvicalyceal system (Nolte-Ernsting et al, 2001). Because of this disadvantage, the overall benefit to imaging is minimal and the use of furosemide is advocated to give similar effects.

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Imaging in computed tomography urography

Computed tomography urography is performed using a multi-detector row helical computed tomography scanner. The images are usually viewed in axial slices (*Figures 1a–c*). However, because of the isotropic or near isotropic details there are a number of image-processing and display techniques. Images should always be reviewed in axial slices before any post-processing begins (Akbar et al, 2004). These techniques include multiplanar reformatting, maximum intensity projections, three-dimensional volume rendering and virtual endoscopy.

Multiplanar reformatting of computed tomography data

This allows reconstruction in any plane. The most popular for computed tomography urography is coronal plane reconstruction but sagittal and oblique planes have been used (*Figure 2*). Oblique planes are of particular value in the evaluation of upper tract transitional cell carcinomas (Dillman et al, 2007).

Maximum intensity projections

These are formed by displaying the voxel with the highest attenuation value along each projected ray that constitutes the image as shown in *Figure 3*. Therefore it will display a specific three-dimensional data set in a single plane (usually coronal). In computed tomography urography this allows the display of the entire urinary tract in one slice, but the detail presented is poor in diagnosing small urothelial filling defects and wall thickenings (Dillman et al, 2007).

Three-dimensional volume rendering

This involves 'summing the contributions from all the voxels along a line from any viewing angle through the data set' (Akbar et al, 2004). A selected range of computed tomography numbers can be shown with different colours and varying levels of opacity. The display of the entire urinary tract in one image can then be rotated and shown in greyscale. This is useful in displaying congenital abnormalities such as urinary tract duplications, horseshoe kidney and renal ectopia. However, it is not useful in detection of small renal lesions and can only show the luminal surface of the ureters and bladder (Dillman et al, 2007).

Virtual endoscopy

Virtual endoscopy is a three-dimensional surface rendering technique which allows the display of the internal walls of organs such as the urinary bladder (*Figure 4*). The detection of bladder lesions in virtual cystoscopy was show in one study to have a sensitivity of 90% and specificity of 94% (Kivrak et al, 2009). However, the technique was unable to detect flat lesions, e.g. a carcinoma in situ, thus can miss the early stage of disease diagnosis. Virtual ureteroscopy has been used to detect urothelial tumours and showed a sensitivity of 81% and specificity

Figure 2. Multiplanar reformatting in the coronal plane. Note the 7 mm renal calculus in the left kidney.

of 100% (Takebayashi et al, 2000). It also showed external compression and differentiated strictures from urothelial tumours. The major drawback of both virtual endoscopic techniques is the inability to see urothelial colour and texture and the inability to take representative biopsies for tissue analysis (Takebayashi et al, 2000; Kivrak et al, 2009).

Figure 3. Image of the upper urinary tract using maximum intensity projection post-processing. Note the benign renal cyst in the left kidney.

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Figure 4. Virtual cystoscopic image demonstrates a 4 mm polypoid lesion (arrow), a proved papillary transitional cell carcinoma in the bladder neck.

Artefacts and errors in computed tomography urography

Diagnostic problems with computed tomography urography can be grouped into problems with technique, reporting normal anatomical structure and variants as pathology, and benign filling defects and wall thickening interpreted as malignant change.

For partial volume averaging, when small cystic lesions are imaged by computed tomography, the thickness of the slice becomes very important. If the lesion does not occupy the entire thickness of the slice it will be averaged to adjacent renal tissue, falsely increasing the attenuation value of the mass and making it indistinguishable. To correct this, the thickness of the computed tomography slice will have to be reduced to a size smaller than the lesion. Lesions outside but adjacent to the renal tract produce streak artefacts over the lesion and hence attenuation value should be measured in artefact-free areas. The spleen can have a similar artefact effect on the upper pole of the left kidney simulating a renal lesion (Akbar et al, 2003).

Patient movement, especially that caused by breathing, will produce images simulating the presence of pathologies such as perirenal lymphoma. To overcome this, the radiologist needs to look for similar findings in the liver, the other kidney or the anterior abdominal wall (Shirkhoda, 1991; Akbar et al, 2003).

Computed tomography urography is usually recorded in unenhanced, nephrogenic and excretory phases. If the images are acquired 25–80 seconds after intravenous contrast the corticomedullary phase will be seen. In these circumstances a solid lesion may be interpreted as normal renal tissue when only unenhanced and corticomedullary phase images are used, giving a false negative result. By the same token images taken only during the nephrogenic phase will identify poorly enhanced renal medulla as renal tumours, producing false positive results. Excretory phase imaging occasionally produces streak artefacts especially when Gastrografin (oral non-ionic), given concurrently for the evaluation of the intestinal tract, is excreted via the kidneys (Cohan et al, 1995; Akbar et al, 2003). In rare instances delayed phase imaging will be required to locate ileal conduits (Akbar et al, 2004).

Normal anatomy can sometimes mimic significant pathology. Benign filling defects caused by mucus, blood clot, renal calculi, ureter of an ileal loop that crosses the midline or simple ureteral kinks can be misdiagnosed as urothelial tumours. Thickening of the wall of the upper urinary tract or urinary bladder can be benign, e.g. focal trabeculations in the bladder as a result of bladder outflow obstruction. There are no characteristic computed tomography urography findings to differentiate these from transitional cell carcinomas and hence cystoscopy is essential (Dillman et al, 2007).

Radiation dose

When investigations move away from conventional plain film radiology to computed tomography scanning there will always be an increased radiation dose to the patient. With that in mind is it important to note that the background radiation dose in the UK is 2.7 mSv and in the United States is 6.2 mSv. In computed tomography urography the effective calculated radiation dose has been reported as 25–35 mSv (Caoili et al, 2002). Compared to conventional intravenous urography Nawfel et al (2004) reported that computed tomography urography has a mean effective dose of 14.8 ± 3.1 mSv, which is one and a half times that of their own series of intravenous urography using 11 plain films.

Reduction in the radiation dose has adversely affected the spatial resolution of the diagnostic image. Important factors to consider when adjusting the dose of contrast agent is the patient's age and the nature of the clinical presentation. In patients with a known or high degree of clinical suspicion of malignancy the radiation dose poses less of a risk than in imaging for benign conditions. Another consideration is in children and pregnant women where an alternate investigation should be sought.

To reduce the dose of computed tomography urography, many clinical and technical protocols have been developed. Clinically, ideal computed tomography urography images should be taken during its three phases (unenhanced, nephrographic and excretory). Applying such a blanket rule is not ideal so, depending on the clinical problem in question, tailored protocols such as split-bolus and triple-bolus intravenous contrast techniques can lower radiation dose as fewer scans are done. Another proposed method of reducing the radiation dose is to apply individualized protocols for conditions grouped into three categories (*Table 1*):

1. Benign disease (low risk)
2. Benign diseases to extensive malignant diseases (intermediate to high risk)
3. Malignant disease (high risk).

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Table 1. Proposed protocol for number of computed tomography urography phases used according to type of disease

Disease type	Risk	Indications	Computed tomography urography phases
Benign	Low risk	Congenital anomalies, hydronephrosis – benign cause, traumatic ureter lesions	One
Benign to extensive malignant	Intermediate to high risk	Haematuria – low/medium risk transitional cell carcinoma or renal cell carcinoma, complex urinary tract infection, chronic urolithiasis and percutaneous nephrolithotomy or nephrolithotripsy planning, urinary diversions post-cystectomy, extra-urinary tumours with involvement of the urinary tract	Two
Malignant	High risk	Haematuria – high risk transitional cell carcinoma or renal cell carcinoma, hydronephrosis – malignant cause, medullary and papillary necrosis	Three

From Van Der Molen et al (2008)

In the first category only a combined nephrogenic-excretory phase is used, in the second category an unenhanced and combined nephrogenic-excretory phase is used and in the third category a standard three-phase study is done. Applying this type of protocol-based approach will make it easier to tailor and protect both high and low risk groups (Van Der Molen et al, 2008).

Reducing the tube current-time-product and tube voltage will reduce radiation dose but produce poor images with extensive image noise. In animal models, scanning the urinary tract during the different phases at different tube current-time-product was reduced to an optimal level of 70 mAs with a fixed voltage of 120 kV. This reduced the radiation dose but still retained a good quality image undisturbed by image noise (Kemper et al, 2007). Applying similar protocols to humans would result in effective doses of 3.3 mSv in men and 5.1 mSv in women using 4-slice computed tomography. Using 16-slice computed tomography in applying a variable tube current-time-product to computed tomography urography phases – unenhanced at 40 mAs, nephrogenic at 125 mAs and excretory at 70 mAs – resulted in a total effective dose of 6.5 mSv in males and 8.5 mSv in females (Stamm and Nagel, 2002). This is a marked reduction from the 25–35 mSv currently used in multi-phase computed tomography protocols. These automated tube current protocols have a 10–30% reduced radiation dose without loss of image resolution (Greess et al, 2000). Until now only the tube current-time-product (mAs) has been reduced but the effect of reducing the tube voltage less than 120 kV may allow for some increase in tube current-time-product so that the contrast and clarity of the images will be of diagnostic quality.

Conclusions

Computed tomography urography is an essential investigative tool in the management of urological conditions. It provides both detailed high quality imaging and the versatility of producing the images in different planes. These features have to be balanced with the high dose of radiation implicated in the use of computed tomography urography. Different protocols have been suggested in an attempt to minimize the radiation dose. Randomized control trials will need to be conducted to determine the type of protocol for specific urological conditions in trying to minimize radiation dose. The second part of this review will focus on how these computed tomography urography techniques and technological advances have become pivotal in the management of common urological conditions. BJHM

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Conflict of interest: none.

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KEY POINTS

- Computed tomography urography is the use of contrast-enhanced computed tomography scanning to image the urinary tract.
- Advances in computed tomography software technology provide clinicians with effective three-dimensional volume rendering and display of images in various planes.
- The majority of computed tomography urography techniques require little or no patient preparation.
- Imaging protocols have been developed to reduce the high radiation dose associated with computed tomography urography.

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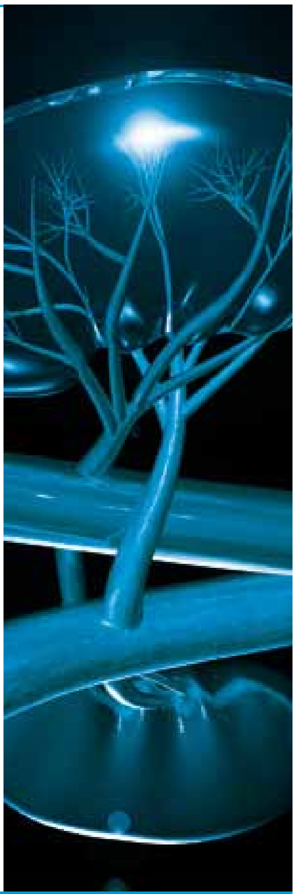

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