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CT urography: principles and indications

CT urografija: načela i indikacije

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Abstract. CT urography (CTU) is an imaging method tailored specifically for the evaluation of the upper urothelial tract and urinary bladder. High diagnostic accuracy in detecting primary and recurrent urothelial tumours, their differentiation from benign lesions, anatomic variation and malformation characterization, and evaluation of important pathology in the surrounding tissues, renders CTU a valuable imaging study of the urothelial tract. Haematuria, initial staging and post treatment follow up of upper urinary tract and bladder malignancies are the most important indications for CTU. Triple phase and split bolus techniques are most commonly used CTU protocols that consist of a non-contrast, nephrographic, and excretory phase, obtained by three or two acquisitions. CTU scanning protocols are tailored to achieve adequate image quality with optimal opacification and distension of the urinary tract at the lowest achievable radiation dose within the range of 5-15 mSv, comparable to the doses of intravenous urography. Detailed patient history, clinical examination, and urine analysis are essential for proper patient selection and targeted CTU protocol, which are the most important tools for increasing diagnostic accuracy and lowering patient radiation dose of CT urography.

Key words: computed tomography; hematuria; urography; urologic neoplasms

Sažetak. CT urografija (CTU) je slikovna metoda specifično prilagođena oslikavanju i procjeni gornjeg mokraćnog sustava i mokraćnog mjehura. Visoka dijagnostička točnost u detekciji primarnih i recidivnih tumora urotela, razlikovanje malignih od benignih lezija, karakterizacija anatomskih varijacija i malformacija te procjena relevantnih patomorfoloških promjena u okolnim tkivima čine CT urografiju vrijednom metodom za oslikavanje mokraćnog sustava. Hematurija, inicijalna procjena proširenosti i praćenje tumora gornjeg mokraćnog sustava i mokraćnog mjehura najvažnije su indikacije za CTU. „Triple phase" i „split bolus" tehnike su najčešće korišteni CTU protokoli koje sačinjavaju nativna, nefrografska i ekskretorna faza, dobivene skeniranjem regije tri ili dva puta. CTU protokoli skeniranja su dizajnirani s ciljem ostvarivanja najbolje kvalitete slike te optimalne distenzije i opacifikacije mokraćnog sustava uz najmanju moguću dozu zračenja, u rasponu od 5 – 15 mSv, što je usporedivo s dozama zračenja intravenske urografije. Detaljna anamneza, klinički pregled i analiza urina ključni su za pravilan probir pacijenata i ciljani odabir CTU protokola, te su ujedno najučinkovitiji način poboljšavanja dijagnostičke točnosti i smanjivanja doze zračenja CT urografije.

Ključne riječi: hematurija; kompjutorizirana tomografija; urografija; urološke neoplazme

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INTRODUCTION

CT urography (CTU) is an imaging method tailored specifically for the evaluation of the upper urothelial tract and urinary bladder. High diagnostic accuracy in detecting primary and recurrent urothelial tumours, their differentiation from benign lesions, anatomic variation and malformation characterization, and evaluation of important pathology in the surrounding tissues renders CTU a valuable imaging study of the urothelial tract. Relatively high radiation dose was the only downside of CTU technique. However, multidetector CT technology advancement and protocol adjustment for the individual patient, enables significant radiation dose reduction within ranges comparable to intravenous urography (IVU).

INDICATIONS

Haematuria

Haematuria can be caused by many benign and malignant conditions located anywhere within the urinary system and it is the most common symptom encountered in the clinical practice. CTU has completely replaced IVU, retrograde ureteropyelography and ultrasonography (US) as the imaging modality of choice in the high risk patient population who present with macrohaematuria, are older than 40 years and carry additional risk factors for urothelial malignancy[1-6]. In this clinical setting the benefit of high sensitivity, specificity and diagnostic accuracy of CTU for upper urinary tract carcinoma detection of 93.5-95.8%, 94.8-100%, and 94.2-99.6%, respectively, outweighs the cost of higher patient radiation exposure compared to other imaging modalities[4]. Current guidelines by the American College of Radiology and the European Society of Urogenital Radiology recommend additional cystoscopy in the evaluation of high risk patients with macrohaematuria. However several studies have shown that CTU is comparable to flexible cystoscopy in excluding and detecting bladder cancer with sensitivity, specificity, positive and negative predictive values of 0.93, 0.99, 0.98, and 0.98, respectively[5,7-9].

Low and medium risk patients presenting with painless microhaematuria require thorough clinical assessment and follow up before proceeding with the appropriate imaging modality. The diagnosis of microhaematuria needs to be correctly established by the findings of three or more red blood cells per high powered field on a properly collected urinary specimen. The most common causes such as vigorous exercise, menstruation, infection, and recent urologic procedure or trauma need to be excluded by detailed history and physical examination. When those are excluded, renal function testing, cystoscopy and CTU are indicated. The American Urological Association asserts CTU over US and IVU as the imaging modality of choice for the evaluation of microhaematuria based on the evidence that the risk of missing a significant pathology requiring treatment is significantly higher than the radiation burden of an optimally performed CTU[1]. Patients with negative initial work up and persistent microscopic haematuria should undergo yearly urine analysis for two consecutive years. If urine analysis is negative, patients can be released from care. If there is persistent haematuria complete imaging follow up should be considered in 3-5 years upon clinicians decision[1].

CT urography is the modality of choice for imaging the pelvicalyceal system, ureters and urinary blader. It has replaced other methods, particularly IVU. Haematuria in selected patients, staging and follow-up of urothelial malignancies, evaluation of congenital and post treatment anatomy distortions, trauma, complicated infections, and 3D planning for difficult percutaneous nephrolithotomy are indications for CTU.

Upper urinary tract tumours

CTU has the highest diagnostic accuracy in the initial evaluation of upper urinary tract cancer (Figure 1). It is essential for TNM staging, detection of synchronous or metachronous urinary tract tumours, and post treatment follow up. CTU enables detection of very small tumours (around 5 mm), and those that present only as urothelial wall thickening. Moreover, it is possible to evaluate periureteric spread, differentiate organ confined (stage T1 and T2) from locally invasive

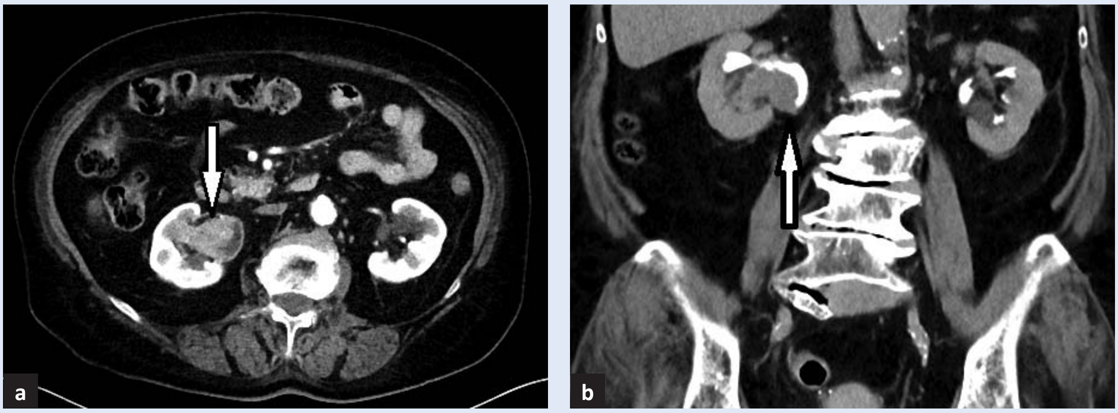

Figure 1 Transitional cell carcinoma of the pelvicalyceal system of the right kidney shown in a) nephrographic and b) excretory phase.

(stage T3 and T4) disease, and asses nodal or distant metastases[4,10]. This information pertinent to patient management and outcome are not obtainable by IVU. In addition, CTU has a high negative predictive value (0.98) for bladder lesions which occur in 40% of patients with upper urinary tract tumours, possibly obviating the need for further invasive diagnostic procedures when no suspicious bladder lesions in patients with upper urinary tract cancer are detected[9-11].

Urinary bladder tumours

Urinary bladder transitional cell carcinoma (TCC) has the highest recurrence rate for all tumours, and 2-4% of patients will have synchronous or metachronous tumour in the upper urinary tract. Thus evaluation and surveillance of the whole urinary tract is mandatory initially and in the post treatment follow up[12-14]. Cystoscopy and deep biopsy are still gold standard in T staging of urinary bladder TCC, especially in superficial tumours. However, in addition to a good detection rate and positive predictive value for diagnosing primary bladder tumours, CTU has the benefit of perivesical tumour spread assessment (sensitivity and specificity 89-92% and 95%-98%, respectively), accurate staging of T3 and T4 tumours, assessment of nodal and distant abdominopelvic metastases, detection of synchronous TCC in the upper urinary tract, and recurrence after transurethral resection (TUR) or radical cystectomy (Figure 2)[14,15]. A study by Kim et al. showed

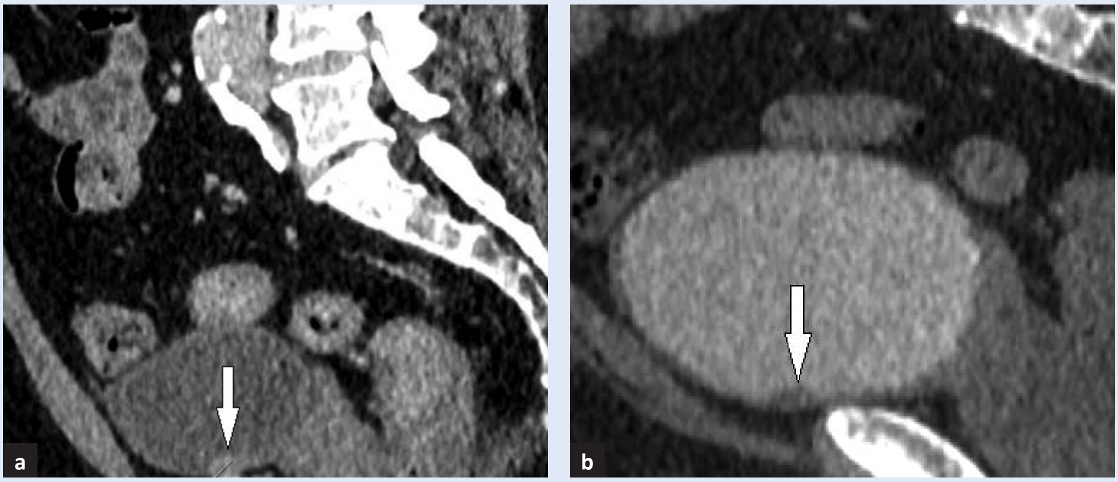

Figure 2 Sagittal reformatted images of a small (< 10 mm) urinary bladder tumour detected on CT urography in a) nephrographic phase as an enhancing lesion, and b) excretory phase as a contrast filling defect.

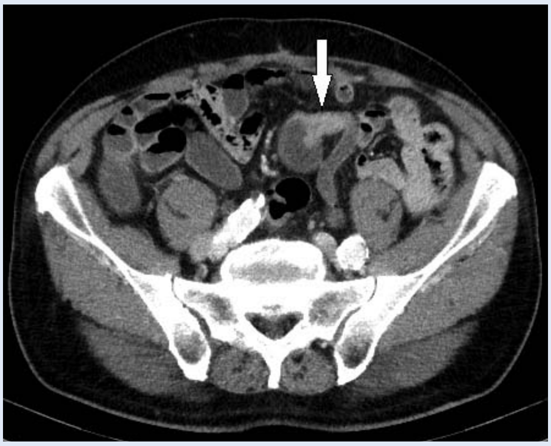

Figure 3 Recurrent transitional cell carcinoma at the anastomosis of the left ureter and neobladder after radical cystectomy seen on axial images as the enhancing wall thickening in the nephrographic phase.

that CTU has the accuracy of 91.7% in detection of recurrent TCC in the bladder after TUR, which was comparable to the reported 95% accuracy of cystoscopy[11]. CTU is essential after radical cystectomy for invasive bladder TCC in assessing post-surgical complications and recurrent or metachronous disease in a complicated setting of distorted anatomy of both genitourinary and gastrointestinal tracts (Figure 3)[16].

Other

Other important indications for CTU are congenital conditions, hydronephrosis, iatrogenic or non-iatrogenic urinary tract trauma, 3D planning for difficult cases of percutaneous nephrolithotomy, and complex urinary tract infections, such as tuberculosis[2,3,17].

MR urography combined with US and/or retrograde pyelography is the alternative imaging modality in patients with relative or absolute contraindications for CTU such as renal insufficiency, contrast allergy, pregnancy, young age and frequent examinations[1].

Indications for CT urography are summarized in Table 1.

TECHNIQUES

Thin-slice multidetector CT imaging and intravenous contrast application are mandatory for evaluating the urothelial tract. Thin-slices enable sufficient spatial resolution required for optimal detection and evaluation of the subtle urothelial tract pathology. Imaging in all three planes and 3D reformations help analyse normal anatomy, characterize and localize pathology, congenital malformations and complex post-surgical anatomical relations of the urinary tract.

Triple phase and split bolus techniques

CTU scanning protocols are tailored to achieve optimal opacification and distension of the urinary tract. Standard CTU protocols consist of three phases acquired in three or two aquisitions: a non-contrast, nephrographic and excretory phase. Non-contrast images are essential for detecting urinary tract stones, intralesional fat and calcification, and differentiation of hyperdense blood clots and non-enhancing benign lesions from malignant masses. Detection of enhancing malignant urothelial lesions or wall thickening that are more hyperdense than the surrounding urine and conspicuity of kidney lesions are highest in the nephrographic phase (80-100 s after the start of contrast injection). Homogenous opacification and adequate distension of the urinary tract in the excretory phase (5-12 minutes after contrast injection) al-

Table 1 CT urography indications

CT urography indications	Comment
Macrohaematuria	Method of choice in patients over 40 years. Complementary to ultrasound and cystoscopy in younger patients.
Microhaematuria	Complementary to ultrasound and cystoscopy after excluding infection, trauma, intensive exercise, mentrual bleeding and kidney disease.
Detection, staging and surveillance of urothelial tumors	Method of choice for upper urinary tract malignancies. Comparable to cystoscopy for bladder carcinoma. Evaluation of disease spread in abdomen and pelvis.
Obstruction, trauma, congenital abnormalities, percutaneous nephrolithotomy, complex infections	CT urography in excretory phase is sufficient for most indications.

lows detection of subtle filling defects representing small lesions (5-15 mm) in the pelvicalyceal system, ureters or the urinary bladder, in addition to comprehensive overview of the anatomic relations[18].

Triple phase and split bolus CTU technique are most commonly used, although there is no universally accepted scanning protocol serving as the gold standard. In the triple phase technique the unenhanced scan of the abdomen and pelvis is followed by two separate scans in the nephrographic and excretory phase after intravenous administration of 100-150 ml of nonionic iodinated contrast agent at the rate of 2-3 ml/s. Split bolus technique is designed to image the urinary tract simultaneously in the combined nephrographic and excretory phase: after the unenhanced scan and the application of 30-50 ml of contrast agent at the rate of 2-3 ml/s, the second contrast bolus of 80-100 ml at the same rate is administered 5-12 minutes after the first, followed by image acquisition with a 100 s delay[19-22]. A graphic display of CTU

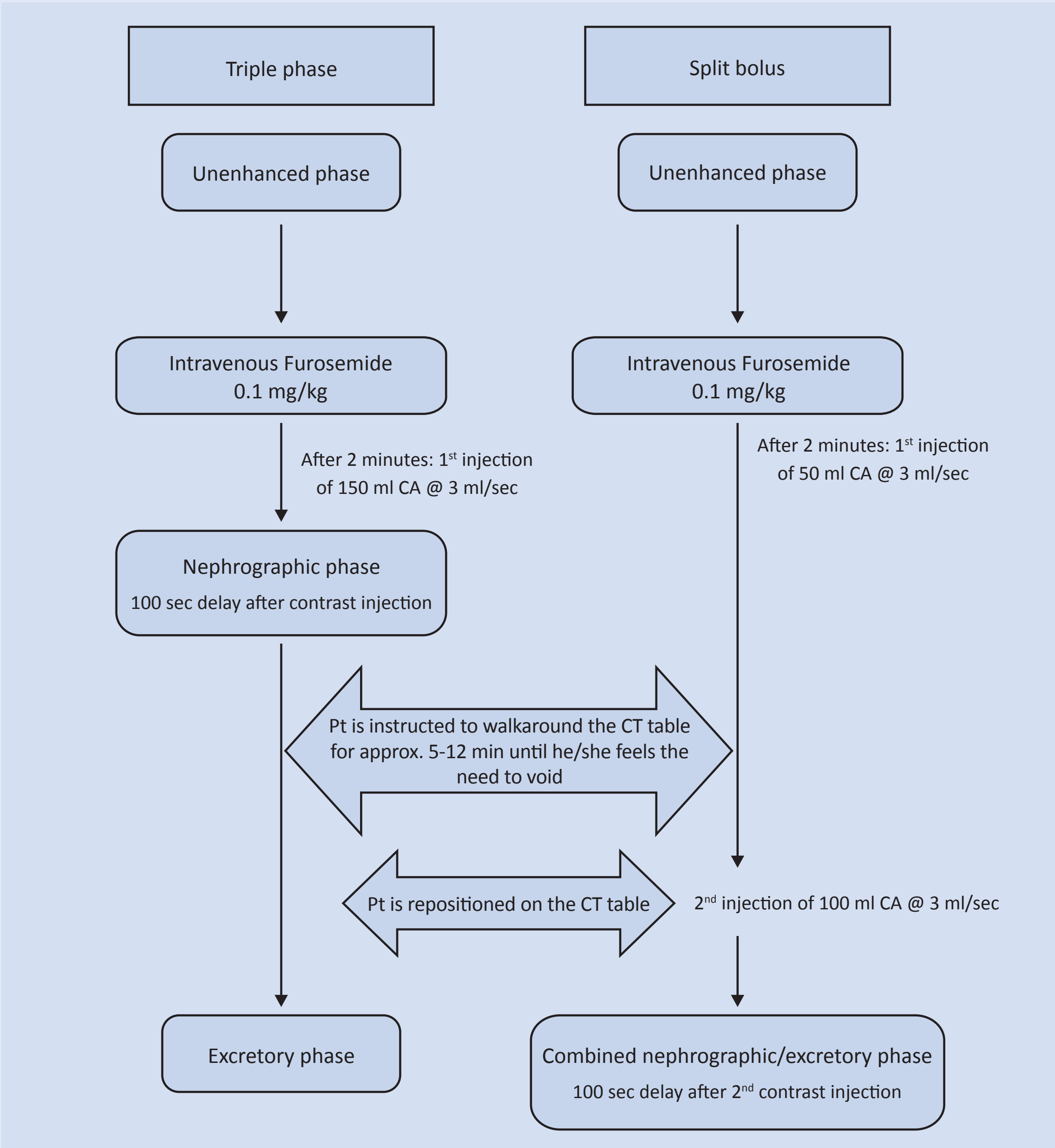

Figure 4 Diagram of the CT urography protocols used at our institution. Patients are instructed to empty their bladder 60 minutes before the examination and to drink 1000 ml of water over the next 20-30 minutes.
CA contrast agent; Pt patient

protocols used at our institution is shown in Figure 4. The advantage of split bolus technique is radiation dose reduction by 30-50% compared to the triple phase protocol, which is an important consideration when imaging younger patients[23]. Detection of small lesions, especially in the distal ureter, in the combined nephrographic and excretory phase may theoretically be lower due to suboptimal distension and lower contrast resolution between the hyperdense enhancing lesion and the surrounding opacified urine. However, studies did not show significantly inferior diagnostic accuracy of split bolus compared to the triple phase technique[22,23].

Promising imaging techniques

Few studies have shown that urothelial tumours opacify the strongest 60-80 s after intravenous contrast application, suggesting that portal venous (PV) phase increases the diagnostic accuracy of CTU by significantly improving bladder tumour detection compared to the nephrographic phase[24,25]. Dual energy CT technology has the advantage of computing virtual non-enhanced from the contrast enhanced images, thus reducing the number of image acquisitions required for performing three phase or split bolus CTU. However, further research is needed to establish the correlation between attenuation values of virtual and real non-enhanced images[26,27].

Manoeuvres for achieving optimal urinary tract distension and opacification

To achieve optimal urinary tract distension and opacification many additional manoeuvres and strategies have been employed, such as abdominal compression, supine and prone positioning of the patient on the CT table, the "log rolling" technique, oral hydration, intravenous saline infusion, application of intravenous diuretics and buscopane. Oral hydration with 750-1000 ml of water over 60 minutes before the examination and intravenous injection of 0.1 mg/kg (maximal dose of 10 mg) of furosemide 2-3 minutes prior to contrast injection have been proven superior to other techniques[28-30]. Optimally timed and sufficient oral hydration is a simple method of inducing diuresis, contrast excretion and distension of the pelvicalyceal system, ureters and the urinary bladder, which is important for lesion detection in all phases[29]. Additional furosemide ensures continuous diuresis and homogenous opacification of the urinary tract resulting in lower attenuation values of the excreted urine. This diminishes possible streak artefacts from the overly dense urine and increases contrast resolution between the enhancing intraluminal lesions and the surrounding opacified urine, which is especially important for lesion detection in the combined nephropyelographic phase in the split bolus protocol[28,30]. Attention should be paid not to administer furosemide to patients with known allergy to furosemide or other sulfa drugs, patients with systolic blood pressure under 90 mmHg, acute renal colic and urinary tract obstruction.

High diagnostic accuracy for urinary tract pathology detection and characterization on CTU overcomes the cost of radiation burden to the patient. Technology advances and protocol adjustments enable significant radiation dose reduction. However, diligent patient selection remains the best method for maintaining the cost benefit ratio in favor of the patient.

RADIATION DOSE REDUCTION STRATEGIES

At the beginning of the CTU technique the reported radiation dose was in the range of 15-25 mSv for triple phase and 10 mSv for split bolus technique, which is about 1.5 times more than the dose of IVU[31]. However, a significant dose reduction has been achieved by modifying scanning parameters and CTU protocols. Dahlman et al. reports dose reduction of a triple phase CTU protocol from 16.2 to 9.4 mSv by performing low dose unenhanced and excretory phase (100 kV, reference dose of 20mAs$_{eff}$ and 40 mAs$_{eff}$, respectively)[32]. Fewer acquisitions in the split bolus technique reduce the radiation dose by 30-50%. Recently introduced iterative reconstruction algorithms improved image quality and allowed dose reduction by additional 40-50% with reported radiation dose of 6. 1 mSv for a triple phase protocol, and possible split bolus study at 4.2 mSv[33-35]. Dual energy CT technology offers even more dose reduction by omitting the unenhanced phase and computing the virtual unenhanced images, however this technique is not yet established in the clinical setting and further research is needed.

CONCLUSION

CTU is the imaging modality of choice for evaluating pelvicalyceal system, ureters and urinary bladder and is replacing IVU. Haematuria, initial staging and post treatment follow up of upper urinary tract and bladder malignancies are the most important indications for CTU. High diagnostic accuracy of CTU outweighs the radiation burden of this imaging technique in selected patient groups. Detailed patient history, clinical examination, and urine analysis are essential for proper patient selection and targeted tailoring of CTU protocol, and therefore remain the most important tools for patient radiation dose reduction.

Conflicts of interest statement: The authors report no conflicts of interest.

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