Acta Scientific MEDICAL SCIENCES (ISSN: 2582-0931)

Volume 6 Issue 1 January 2022

Research Article

Dose Exposure and Diagnostic Capability of Split Bolus Computed Tomography Urography (CTU): Comparison with Single Bolus Technique

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Received: September 27, 2021

Published: December 08, 2021

Abstract

Objectives: To compare CT urography (CTU) split bolus with standard protocol in terms of urinary tract opacification, parenchymal and vascular enhancement, and radiation dose exposure. To assess split bolus CTU diagnostic capability.

Methods: Forty-eight patients (18-83 years) were retrospectively analysed: 24 (study group) performed a split-bolus CTU (combined nephrographic-excretory phase), 24 (control group) a single bolus protocol. On combined and portal venous phases, quantitative analysis of intraluminal opacification and parenchymal-vascular enhancement (HU) was achieved by placing regions of interest (ROI) in urinary tract, liver, spleen, kidneys, abdominal aorta and inferior vena cava. The corresponding mean HU values were compared between 2 groups. Qualitative analysis of urinary intraluminal opacification was performed by two radiologists using a four-point scale; inter-observer agreement was calculated. Radiation dose was calculated as Dose Length Product (DLP) and Computed Tomography Dose Index Volume (CTDIvol). The diagnostic capability was evaluated using a 2-point scale, using histology, imaging follow-up and endoscopy as reference standard.

Results: The split-bolus protocol demonstrated lower mean urinary attenuation compared to the control group but no differences in quality of urinary tract opacification or in parenchymal-vascular enhancement. Mean DLP was lower ($p = 0.045$) in the study group (reduction of 37%). Split-bolus protocol answered the clinical question in 22/24 cases.

Conclusions: With a comparable urinary tract opacification, parenchymal organs and vessels enhancement, split-bolus CTU results in a proper accuracy with a dose reduction of 37%, as compared to single-bolus protocols.

Keywords: Computed Tomography; Split Bolus; Radiation Dose; Kidneys; Urinary Tract

Abbreviations

CT: Computed Tomography; CTU: Computed Tomography Urography; ACR: American College Radiology; HU: Hounsfield Units; CM: Contrast Medium; BT: Bolus Tracking; ROI: Region of Interest; DLP: Dose Length Product; CTDI vol: Computed Tomography Dose Index Volume; SD: Standard Deviation; CI: Confidence Interval; MDCT: Multidetector Computed Tomography; IVC: Inferior Vena Cava; MRI: Magnetic Resonance Imaging; MPR: Multiplanar Reconstruction; MIP: Maximum Intensity Projection

Introduction

CT urography (CTU) is the primary imaging modality for the simultaneous evaluation of kidneys and urinary tract [1]. It furnishes a complete assessment of abdomen and pelvis through a direct vi-

sualization of organs, vessels, and adjacent structures. Common indications are urolithiasis, urinary obstruction, haematuria workup, urothelial neoplasms, traumatic/iatrogenic ureteral injuries, and urinary tract infections [2]. Additional indications are congenital or post-surgical urinary tract anomalies and any scenario where a detailed evaluation of urinary tract is needed [3].

In these scenarios, considering the potential multiple CT studies that patients may undergo during their disease, radiation dose delivery should be kept as low as possible while preserving an overall diagnostic quality for proper image evaluation [4-6]. A CTU study typically comprises three phases: unenhanced (haemorrhage and stones detection), nephrographic (parenchymal lesions assessment) and excretory (collecting system, ureters, and bladder evaluation). To reduce the number of phases is the easiest tool to obtain dose exposure reduction [7]. Split-bolus techniques can lead to a radiation dose exposure reduction by allowing a combined acquisition of two different contrast-enhanced dynamic phases in one. To the best of our knowledge, split-bolus has been applied in several urological settings, with the original aim to improve urinary tract visualization. Other fields were also explored, with excellent results and significant radiation dose reduction, both in adult and paediatric patients: liver and pancreatic lesions detection and characterization, renal donors' evaluation, acute abdominal pain and pulmonary embolism [8-11]. As per the latest guidelines from the American College of Radiology (ACR), split bolus CTU is mentioned as potential tool for the evaluation of indeterminate renal masses, haematuria, acute onset flank pain with suspicion of stone ad acute pyelonephritis, even employing dual-energy machines. However, split bolus CTU benefits are still unclear, therefore not allowing to consider it as the reference standard in uroradiology [12].

The purpose of our study was to analyse the urinary tract opacification qualitatively and quantitatively, quantitatively evaluate abdominal organ enhancement and report the corresponding radiation dose exposure in split-bolus CTU studies, as compared to single-bolus protocol. The diagnostic capability of split-bolus protocol was also evaluated using histology, follow-up, and endoscopy as reference standard.

Materials and Methods

Study population

We retrospectively analysed 48 patients who underwent CTU between January and December 2015. The main clinical indications for CTU were oncologic disease, urolithiasis, haematuria, hydronephrosis and trauma with suspected urinary injuries.

The patients were divided in 2 groups, according to the scanning protocol. The study group consisted of 24 patients (range 18-83 years; 7 females) scanned with a split-bolus protocol (Figure 1). The control group included 24 patients (range 22-83 years; 9 females) who underwent a standard single-bolus technique. The inclusion criteria were the following: a) age at the time of CT of 18 or older; b) no radical cystectomy; c) no artefacts (i.e., motion or metal devices) impairing image evaluation. A final number of excluded patients has not been annotated. Informed consent was obtained before CT acquisition from all individual participants included in the study. Anonymity and confidentiality of the collected data was insured.

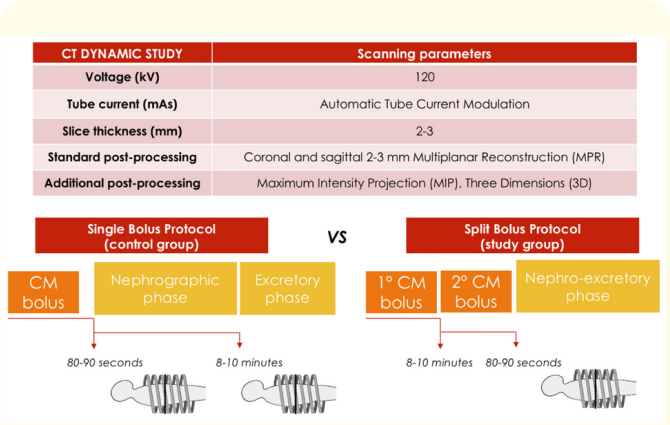

Figure 1: Split Bolus CTU protocol main parameters. Axial images along with multiplanar reconstruction (MPR) are generally used for exam evaluation. Maximum-Intensity-Projection (MIP) and 3D reconstructions are performed in selected cases, to better visualize the main arterial vessels (arterial phase), whole urinary tract anatomy and renal masses relation with collecting system (nephro-urographic phase). MIP are generally performed with a slice thickness of 10 mm and 7 mm interval. CTU: computed tomography urography; BT: bolus tracking.

Scanning protocols: single and split bolus CTU

All CTU were performed on a 64-row scanner (Aquilion, Toshiba Medical), with automated tube current-modulation, to adjust the tube current in real time for image noise maintenance at the

optimal level [13] and a standard 120 kV set up. Patients were positioned prone. Additional supine scanning was not performed in any case. Neither intravenous diuretic drugs nor external abdominal compression were used, as per standard departmental protocol.

A baseline unenhanced scan (diaphragm to trochanter minor) is generally performed during first examinations. It is mainly used for stones detection and to furnish lesions/collections baseline HU values. For standard CTU, iodinated contrast medium (CM; Omnipaque 350, GE Healthcare) was then administered in an antecubital vein at a standard dose of 1.5 ml/kg and a flow rate of 3-3.5 ml/sec, followed by a 30-50 mL saline flush at the same flow rate. An additional injection of 100 mL saline flush (flow rate 1 mL/sec) is performed after the completion of the first CM-saline flush administration, to obtain a proper urine excretion and bladder filling in the excretory phase. Due to the retrospective nature of the study, minor variations in saline flush could not be completely addressed but were considered unlikely affecting the overall urinary tract distension and opacification. After the intravenous administration of a single CM bolus, the standard CTU study protocol is based on the acquisition of portal venous and excretory phases of the volume of interest (upper and whole abdomen, respectively) for most of the pathologies affecting the urinary tract (i.e., stones or suspected infections). The nephrographic phase is performed after 70-100 seconds (average 90 seconds) or 35 seconds using the bolus-tracking (BT) technique (Sure Start) while the excretory phase after 8-10 minutes.

In the split-bolus technique, the total amount of CM is fractionated in two consecutive boluses, with a standard infusion rate of 3.0-3.5 mL/sec: about 40% of the total amount is administered at baseline and the remaining 60% after 8-10 minutes. Approximately 80-90 seconds after the second bolus, a single combined nephro-urographic phase is acquired. The concomitant saline flush administered is equivalent to the standard CTU protocol, in terms of both quantity and infusion rate.

An arterial phase has been additionally acquired in both the study and the control group for renal masses characterization, clear cell carcinoma and urothelial tumors (staging or follow-up), as well as in one traumatized patient (study group). After CM injection, the arterial phase is performed with a time delay of 25-35 seconds or 13 seconds using BT. To this purpose, a single region of interest (ROI) is placed within the aortic lumen using a 120-150 HU threshold. A total of 16/24 patients in the control group and 11/24 patients in the study group required an additional arterial phase acquisition.

Images and data analysis

Two radiologists independently performed images analysis: a consultant (reader 1) and a resident (reader 2), with 10- and 2-years' experience in abdominal CT, respectively. The quantitative analysis was performed by manually placing circular ROI within the opacified lumen of the urinary tract, avoiding calcifications or areas of eventual urothelial thickening, both in the combined nephro-urographic (study group) and excretory phases (control group). ROI's size measurements (including ranges) were not performed but the largest area of the lumen was always covered. Mean HU values for each segment were recorded and compared between the groups.

For ROI placement, six specific anatomic sections were identified: left and right renal pelvis; upper, middle, and lower portions of left and right ureters; bladder. The ureters portions were identified as follows [14]: the upper portion extends from the ureteropelvic junction to the upper border of the sacrum; the middle portion continues from the upper to lower borders of the sacrum; the distal portion continues from the lower border of the sacrum to the ureterovesical junction.

Then, the readers independently performed a qualitative analysis of urinary tract opacification (pyelocaliceal system, ureters, bladder) in both groups, by using a 4-point scale: 0 none, 1 poor, 2 diagnostic and 3 excellent. For split-bolus diagnostic capability (0 no answer given, 1 question satisfied), the final diagnosis of the most experienced reader was considered. To assess diagnostic capability in answering the underlying clinical question further imaging studies, follow up, endoscopy and/or histology were used as standard reference.

Vascular and parenchymal enhancement were also measured, respectively on portal venous phases in the control group and on combined nephro-excretory phases in the study group. Vessels contrast enhancement was achieved by placing circular ROI in the lumen of infrarenal IVC and infrarenal abdominal aorta (approximately same level), avoiding any intraluminal filling defect, mural

thrombosis or atherosclerotic changes. Parenchymal enhancement was analysed by placing ROI on liver, kidneys and spleen (avoiding vessels), as follows: 3 in liver segments II, III and IV (main portal vein bifurcation level); 3 in the upper, middle and lower poles of each kidney; 1 in splenic parenchyma (hilum level). Attenuation values (HU) recorded from ROI placed on liver and kidneys were then averaged, obtaining a single measurement for each organ.

For each CT examination, radiation dose exposure was annotated in terms of DLP (mGy*cm) and CTDI vol (mGy), as automatically calculated by the CT scan. Data provided covered the total acquisition volume, therefore the entire radiation dose derived from the total sum of the acquired phases was considered.

Statistical analysis

Statistical analysis was performed using SPSS software for Windows (version 17.0; SPSS Inc.) and MedCalc for Windows (version 12.7.0.0; MedCalc Software). Age, sex and number of phases acquired were reported in terms of average ± standard deviation (SD) and median values for each group. The Student's t test was used to evaluate differences between the study and control group in terms of patients' mean age, while the Chi-square test was used to evaluate differences in terms of sex. HU, DLP e CTDI of both groups were reported as mean values, SD and median. The Mann-Whitney U test was used to evaluate differences between the study group and the control group in terms of mean attenuation values calculated in urinary tract, vessels and parenchymal organs. Using the same test, we also compared the radiation dose exposure and image quality scores between the two groups. A $p < 0.05$ was considered statistically significant. For split-bolus CTU studies the interobserver agreement of image quality scores was determined by Cohen's kappa with 95% confidence intervals (CI): k values < 0 indicate poor agreement, 0-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial e 0.81-1.00 almost perfect, as described by Landis e Koch [15].

Results and Discussion

No significant differences were observed in terms of age or sex in both groups. As expected, the number of phases acquired (average ± SD; median) was lower in the study group than in the control group, respectively 2.38 ± 0.71; 2.50 and 3.79 ± 0.93; 4.00.

The quantitative analysis deriving from ROI placement in the urinary tract demonstrated overall higher HU values in the standard CTU protocol than in the split-bolus. As reported in table 1, we also found a progressive partial reduction of HU values from renal pelvis down to the bladder. Except for the bladder, that demonstrated the lower quantitative values, these differences were always statistically significant ($p < 0.05$). No statistically significant differences regarding vascular, renal, hepatic, and splenic enhancement were found by quantitative analysis (Table 1b).

Anatomic site	Quantitative analysis (HU)		
	Study group	Control group	p-value (p < 0.05)
Left renal pelvis	908.7 ± 494.7	1326.2 ± 637.0	0.043*
	968.6	1221.6	
Right renal pelvis	877.1 ± 492.1	1252.7 ± 544.6	0.037*
	910.0	1121.4	
Left ureters	810.0 ± 531.7	1113.8 ± 581.5	0.044*
	733.7	891.6	
Right ureters	655.3 ± 444.0	1126.8 ± 555.4	0.002*
	663.5	1027.2	
Bladder	604.9 ± 381.0	939.4 ± 675.2	0.080

Table 1a

Anatomic site	Quantitative analysis (HU)		
	Study group	Control group	p-value (p < 0.05)
Liver	107.3 ± 19.54	108 ± 19.56	0.526
	105.5	105	
Spleen	112 ± 17.39	108.3 ± 18.78	0.3182
	110	101.5	
Left Kidney	184.8 ± 24.86	182.5 ± 26.97	0.9252
	186.5	187	
Right Kidney	184.4 ± 25.8	179.6 ± 22.94	0.5337
	186.5	180	
Aorta	161 ± 26.52	150.7 ± 22.14	0.1052
	155.5	147.5	
Inferior vena cava	131.2 ± 18.51	123.2 ± 18.76	0.1422
	127	119.5	

Table 1b

Anatomic site	CTU protocol	Qualitative analysis				
		Reader 1 (R1)	p-value R1	Reader 2 (R2)	p-value R2	k Cohen R1-R2 (95%CI)
Left pelvis	Split-bolus	2.5 ± 0.6	0.088	2.8 ± 0.5	0.344	0,114 (-0,119 to 0,348)
	Traditional	2.8 ± 0.5		2.9 ± 0.4		0,543 (-0,00895 to 1,000)
Left upper ureter	Split-bolus	2.6 ± 0.9	0.741	2.9 ± 0.3	0.912	0,404 (0,119 to 0,689)
	Traditional	2.6 ± 0.9		2.8 ± 0.7		0,415 (-0,0529 to 0,883)
Left middle ureter	Split-bolus	2.6 ± 1.0	0.633	2.7 ± 0.8	0.909	0,298 (-0,242 to 0,838)
	Traditional	2.8 ± 0.7		2.7 ± 0.8		0,452 (-0,121 to 1,000)
Left lower ureter	Split-bolus	2.2 ± 1.1	0.866	2.4 ± 0.9	0.960	0,706 (0,430 to 0,983)
	Traditional	2.2 ± 1.1		2.4 ± 1.0		0,390 (0,0773 to 0,703)
Right pelvis	Split-bolus	2.7 ± 0.6	0.746	2.9 ± 0.3	0.613	0,375 (0,0457 to 0,704)
	Traditional	2.8 ± 0.5		2.8 ± 0.5		0,538 (0,0687 to 1,000)
Right upper ureter	Split-bolus	2.7 ± 0.8	0.399	2.7 ± 0.6	0.955	0,462 (0,190 to 0,733)
	Traditional	2.5 ± 1.1		2.5 ± 1.1		0,660 (0,299 to 1,000)
Right middle ureter	Split-bolus	2.6 ± 0.8	0.509	2.3 ± 1.1	0.321	0,381 (0,141 to 0,621)
	Traditional	2.3 ± 1.2		2.5 ± 1.1		0,549 (0,225 to 0,874)
Right lower ureter	Split-bolus	1.9 ± 1.1	0.913	2.0 ± 1.1	0.233	0,521 (0,264 to 0,779)
	Traditional	1.9 ± 1.2		2.3 ± 1.1		0,487 (0,168 to 0,807)
Bladder	Split-bolus	1.6 ± 0.8	0.482	1.5 ± 0.7	0.123	0,462 (0,200 to 0,723)
	Traditional	1.8 ± 0.8		1.8 ± 0.6		0,667 (0,460 to 0,873)

Table 1c

Table 1: Summary of quantitative (a, b) and qualitative analysis (c) in the two groups (study and control). Quantitative analysis of urinary tract, performed in the combined (study group) and delayed phases (control group) (a). Quantitative analysis of vascular and parenchymal structures, performed in the combined (study group) and venous phases (control group) (b). Qualitative analysis of urinary tract, performed by 2 readers (R1 and R2) and interobserver agreement (c). HU: Hounsfield Unit. CTU: computed tomography urography.

Data from the qualitative analysis of the urinary tract are reported in Table 1c. Despite a not homogenous inter-observer agreement, the overall opacification of the whole urinary tract was generally rated either diagnostic or almost excellent between the two CT groups, except for the bladder and partially for the lower portion of the right ureter.

Concerning radiation dose exposure, DLP and CTDIvol were lower in the study group as compared to the control group. A statistically significant difference was found only for DLP (1869.29 ± 1103.48 vs 3002.19 ± 2399.76 mGy cm). CTDIvol demonstrated a trend towards reduction (57.29 ± 39.93 vs 97.21 ± 85.91 mGy), even if not statistically significant. Accordingly, the split-bolus allowed a reduction of radiation dose exposure of 37%.

Follow-up, laboratory/clinical data, or final histopathological results were available for 19/24 cases (study group) (Table 2). The mean follow-up was of 9.5 months (range 0.5-24 months). There were 10 true positives (6 benign, 4 malignant), 6 true negative (3 oncological follow-up, 2 suspected urolithiasis, 1 suspected tumor), 2 false negatives (2 flat urothelial carcinomas) and 1 false positive (suspected tumor recurrence). This given, sensitivity, specificity and accuracy of split bolus protocols resulted 0.83, 0.86 and 0.84 respectively. The remaining 5 patients had no further examinations performed at our Institution and were lost at follow up (1 suspected prostate cancer, 3 urolithiasis and 1 hydronephrosis for probable pyeloureteral junction syndrome.

Age	Sex	Clinical indication	Main CT findings	Final diagnosis	Diagnostic proof	TP	FP	TN	FN
70	M	Haematuria	Negative	Flat urothelial carcinoma	Histology (cystoscopy)				X
66	M	Bladder cancer staging	Diverticula. No wall thickening/ enhancement	Flat urothelial carcinoma	Histology (surgery)				X
69	F	Endometrial carcinoma follow up; pelvic nodes and vaginal vault metastasis. Left double J catheter	Left pelvis and ureteral inflammatory changes, worsened hydronephrosis	Stent related polyuria and dysuria	Clinical follow up	X			
83	M	Suspected bladder cancer	Bladder lesion	Invasive bladder cancer	Histology (surgery)	X			
81	M	Bladder cancer follow up	Negative	No recurrence	Cystoscopy and urine cytology			X	
78	M	Bladder cancer follow up	Negative	No recurrence	Cystoscopy			X	
76	M	Haematuria	Prostatic enlarged, detrusor hypertrophy	Benign prostatic hyperplasia (BPH)	Cystoscopy and clinical evaluation	X			
76	M	Suspected left hydronephrosis. Known renal cysts	No hydronephrosis. Bilateral renal cysts	Negative	Emergency department 11 months later for acute abdominal pain; negative ultrasound and urological examination			X	
74	M	Suspected right renal lesion	Right renal lesion	Right renal lesion	Histology by surgery (oncocytoma)	X			
71	M	Bladder cancer follow up	Negative	No recurrence	Cystoscopy, ureteroscopy and urine cytology			X	
70	F	Nephrolithiasis	Left hydronephrosis and bilateral nephrolithiasis	Left multifocal nephrolithiasis	Ureteroscopy, retrograde pyelography and double J catheter	X			
59	F	Left renal function exclusion, left nephrolithiasis	Atrophic left kidney, reduced nephrographic enhancement, delayed urine excretion	Diffuse left chronic pyelonephritis	Histology (surgery)	X			
57	M	Haematuria	Right renal tumor	Right renal tumor	Surgery performed in outside center. Post tumorectomy changes at follow up CT with no local recurrence or metastatic disease.	X			

53	M	Haematuria in bladder cancer follow up	Bladder lesion	Urothelial bladder cancer	Histology (cystoscopy)	X			
50	F	Nephrolithiasis	Left nephrolithiasis	Left nephrolithiasis	Extracorporeal Shock Wave Lithotripsy (ESWL)	X			
50	M	Urachal mucinous adenocarcinoma restaging	Eccentric bladder right posterior wall thickening	Post-surgical changes in the right posterior bladder wall	Cystoscopy and ureteroscopy	X			
49	M	Trauma	Active arterial bleeding in right inferior pubic ramus fracture	Active arterial bleeding by right internal iliac artery branch	Emergency embolization in outside center	X			
31	M	Haematuria	Negative	Negative	Cystoscopy and urine cytology			X	
18	F	Suspected ureteral stone	Negative	Negative	Ultrasound follow up			X	

Table 2: Diagnostic accuracy of split bolus CTU. Clinical or imaging follow-up, cystoscopy and histology were used as standard reference.

MDCT represents the main imaging technique for renal and urinary tract evaluation [16,17], but to the best of our knowledge, no standard CTU protocols have been widely accepted (12). Therefore, the need to acquire at least both the nephrographic and excretory phase is the main background for considering the split-bolus CTU technique. Split-bolus CTU protocol is technically feasible, allowing to obtain in a single volume acquisition the typical findings of the nephrographic (i.e., proper renal parenchyma enhancement, along with liver, spleen and pancreas) and excretory phases (i.e., urinary tract opacification). The high-resolution acquisitions allow performing additional reconstructions (MPR, 3D, MIP), with better visualization of both vascularity and whole urinary tract anatomy, while the collecting system is opacified during the combined nephro-urographic phase.

By employing a dual-energy CT scanner, Karlo., *et al*. [18] reported urinary tract complete opacification in 94% of patients, with a diagnostic accuracy of 98% on a per-renal-unit basis and 96% on a per-patient basis, respectively (excellent inter-reader agreement). To the best of our knowledge, there are no previous reports quantitatively evaluating the urinary tract opacification in split-bolus CTU. The contrast injection fractionation may lead to a slightly higher overall CM dose as compared to that used in a traditional multiphasic study [19]. However, the reported diagnostic efficacy is comparable to the traditional protocols in terms of imaging quality, in accordance to Chow., *et al*. [20]. In our cohort of patients, the CM dose was kept standard to the patient's weight, as aforementioned.

In our study the overall urinary tract HU values resulted significantly lower in the study group, likely because the first bolus, meant for urinary tract opacification, represents 40% of the total amount of CM. The bladder demonstrated the lowest HU values and qualitative scores, but this did not affect the image quality or evaluation of potential lesions (Figure 2). The two independent readers qualitatively scored the overall opacification of the urinary tract as diagnostic/excellent in both groups, despite an inhomogeneous inter-observer agreement. This emphasizes that the split-bolus CTU can allow a proper evaluation of kidneys and ureters, as reported in other studies [21].

Split bolus CTU showed also an excellent diagnostic capability in answering the underlying clinical question (Table 2). The two cases in which the split bolus was inconclusive were mainly blad-

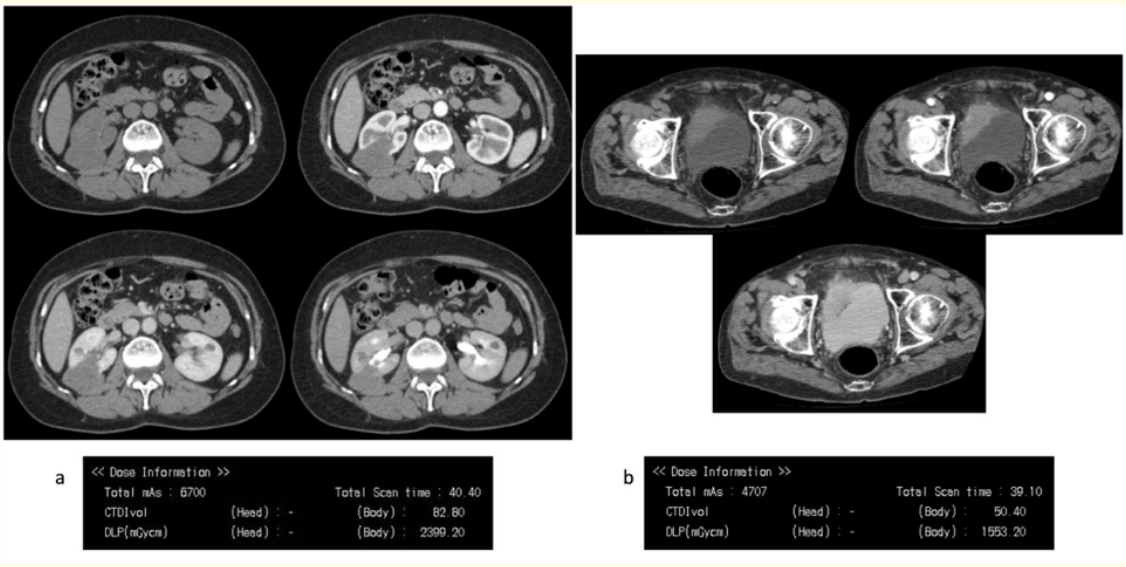

Figure 1: Comparison of radiation dose data obtained in a standard CTU study (a) and a split bolus CTU examination (b). Split bolus CTU was performed for suspected urothelial lesion of the bladder, with an additional arterial phase. Despite the reduced bladder opacification, the CTU examination properly evaluated the neoplastic lesion on the anterior and right-side wall, protruding into the lumen. The concomitant stranding of the adjacent fat is also properly appreciable. The CTDI vol and the DLP are lower in the split-bolus protocol (b), as shown.

der flat tumors, revealed after cystoscopy. To this regard, although MDCT has a sensitivity up to 80-85% in detecting bladder tumours [21], small and flat lesions may be missed [22] and cystoscopy remains the gold standard [23].

The 2 readers observed comparable mean attenuation values in the enhanced liver, spleen, aorta, IVC and kidneys between the groups. HU values in the liver, spleen and IVC were higher than those observed in three different split-bolus protocols by Lee., *et al*. [24] and in line with those observed by Chen., *et al*. in aorta and liver [25]. Given the good enhancement, both readers were able to properly identify and characterize incidental findings in both groups (i.e., simple cystic lesions or aortic atheromatous disease). This was not stated in terms of statistical significance but reported by the readers who denied differences in the interpretative assessment of such findings between standard portal-venous and combined nephro-urographic phases. The benign nature of parenchymal lesions was confirmed by clinical data and follow-up examinations, only in the study group.

In our study, split bolus CTU allowed a radiation dose reduction of 37%. According to the protocol employed, the reported radiation dose exposure for standard CTU examinations ranges from 20 to 66 mSv, [26] compared with a mean effective dose (ED) of 5-10 mSv for intravenous urography [27]. This represents the biggest concern tampering the use of CTU in the daily clinical practice, particularly in young patients (i.e., stones, infections) or for follow-up purposes (i.e., complex renal cysts, treated carcinomas). For these reasons several techniques are currently used to reduce the radiation dose exposure in CT scans. Radiation dose mainly depends on the number of phases acquired, the scanning parameters employed and patient size. As a first approach, radiation dose exposure reduction must be obtained with the lowest number of phases as possible [7]. Another common approach is to lower the tube voltage, mainly employing the Attenuation-based Automated Tube Voltage Selection. This is nowadays provided as a software tool in CT scanners: the iodine attenuation increases as tube voltage is reduced, resulting in higher contrast enhancement [28], and

leading both to radiation dose and CM reduction. This was shown in previous vascular studies performed at 90 and 100 kV [29,30]. Our CTUs were performed using a standard 120 kV setting; therefore, being a retrospective study, it was not possible to attempt any effective reduction in CM dose injected. However, this remains an interesting research goal and a potential concern in patients with renal function impairment, as often those undergoing CTU. Another strategy to decrease radiation dose is to employ iterative reconstruction techniques and/or dual-energy CT, both not available in the employed scanner.

Our study has some limitations, related to its retrospective nature and the small and inhomogeneous study population (clinical indication, phases acquired). There are also some limits to consider while approaching split-bolus CTU protocols (as also standard CTU studies). The arterial phase is not routinely performed; therefore, the protocol may be suboptimal for an accurate staging of tumours occasionally detected and such patients may require additional contrast-enhanced studies (i.e., MRI). The proper timing of double CM bolus is essential to avoid partial/inhomogeneous opacification of the urinary tract; the reduced amount of the first CM bolus may lead to lower HU values of iodinated urine as compared to a standard CTU. However, the final evaluation generally relies on the overall opacification by a qualitative point of view, and this seems to be similar between the two techniques, as reported in our study.

Conclusion

Split bolus CTU demonstrated to combine proper urinary opacification and diagnostic capability, allowing a concomitant significant reduction of radiation dose (about 37%). This may allow an implementation of this feasible technique in the daily clinical practice for patients with diseases affecting the urinary tract.

Acknowledgements

This work was supported in statistical processing by Francesca Pregnolato.

Conflict of Interest

The authors declare no conflict of interest.

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