Original Article

Computed Tomography Urography: Comparison of Image Quality and Radiation Dose between Single- and Split-Bolus Techniques

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Abstract

Introduction: In this study, we aimed to compare the split-bolus and single-bolus computerised tomography (CT) urography and determine if this offers a reduction in radiation dose without compromising image quality. Materials and Methods: A retrospective evaluation was performed on 88 patients undergoing split-bolus CT urography and this was compared to a control group of 101 consecutive patients undergoing single-bolus CT urography. A radiation dose analysis was performed on each subject. Subjects with urinary bladder lesions, hydronephrosis, renal masses or cysts >3 cm in diameter were excluded. All images were classified according to image quality by 2 consultant radiologists. Results: Opacification of the renal parenchyma, pelvicalyceal system, proximal ureters and urinary bladder were comparable between the 2 techniques, whilst image quality of the middle and distal third of the ureters was better using the split-bolus technique. The mean dose length product (DLP) for the single-bolus technique was 1324.1 mGy·cm, whilst that of the split-bolus technique was 885.7 mGy·cm. The mean effective dose reduction was calculated to be 31.1% between the 2 groups. Conclusion: The split-bolus technique gives a reduced radiation dose without compromising image quality. The associated reduction in images is beneficial for data storage and reporting efficiency. As such, our department will adopt the split-bolus technique for young, low-risk patients.

Ann Acad Med Singapore 2018;47:278-84

Key words: Intravenous pyelogram, Intravenous urogram

Introduction

Previous studies have demonstrated that computerised tomography (CT) urography is more accurate in the detection and characterisation of renal masses,[1-5] detection of urinary calculi, urinary tract abnormalities,[6-8] infective/inflammatory renal disorders[9] and for the evaluation of haematuria[10] compared with intravenous urography or ultrasound. However, it is observed that a standard triple-phase CT urography study carries an increase of approximately 1.5 times the effective radiation risk compared with conventional urography.[11-12]

A typical single-bolus, triple-phase CT examination of the urinary system will include non-contrast, nephrographic and excretory phases. In comparison, an alternate split-bolus, dual-phase technique images the urinary system in only the non-contrast and combined nephrographic-excretory phases.

Previous papers have suggested that the radiation dose reduction in a split-bolus protocol is not substantial.[3] It was also reported that limited contrast volume boluses given in a split-bolus technique may result in reduced distension of the distal ureters.[7]

The aim of our study was to determine if a split-bolus technique can produce an equivalent imaging quality to the single-bolus technique. Our secondary aim was to confirm that the split-bolus technique will reduce patient radiation dose.

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Materials and Methods

The study was approved by the hospital's Centralised Institutional Review Board. (CIRB).

Study Population/Patient Selection

Patients who had a split-bolus CT urography between September 2012 and February 2013 were selected. The decision to submit patients for a split-bolus study was made independently by the hospital urology team, who selected patients who were young and at low risk of having an urothelial malignancy. There were a total of 88 patients in this group. The control group comprised 101 consecutive subjects who had undergone a single-bolus triple-phase examination in the same period. A statistician was consulted to confirm adequacy of sample size.

Subjects with a malignant renal mass, renal cyst larger than 3 cm, urinary bladder lesions or hydronephrosis were excluded as these may confound the degree of urinary tract opacification. One subject in the control group had right renal agenesis but remained in the study although only the normal left urinary tract was evaluated.

Evaluation

All images obtained from both groups were analysed independently by 2 consultant radiologists.

The quality of opacification of the renal parenchyma, pelvicalyceal system and opacification/distention of the proximal ureters, middle ureters, lower ureters and urinary bladder were assessed using a 3-tiered scale: 1) Tier 1: Poor or streaking opacification/distention, suboptimal for diagnosis; 2) Tier 2: Incomplete opacification/distention, sufficient for diagnosis; and 3) Tier 3: Complete opacification/distention, optimal for diagnosis.

Figure 1 is an example of the degree of renal parenchymal enhancement expected in Tier 2 and Tier 3 groups. Figure 2 demonstrates a 3D coronal reconstruction of ureters taken from subjects allocated to Tier 1, Tier 2 and Tier 3 groups.

Scanning Protocols

In both groups, subjects were given 500 ml of water orally, 20 to 30 minutes prior to commencing the examination. There was no diuretic, saline infusion or abdominal examination administered during examination. The patients were mobilised outside the scan room prior to acquisition of the excretory phase. Coverage of both protocols is from just above the kidneys to the pubic symphysis.

The imaging studies were performed on 2 different CT scanners, a 64-slice CT scanner (Aquilion, Toshiba Medical Systems) and a 320-slice CT scanner (Aquilion One 320, Toshiba Medical Systems). In the control group, the 64-multi-detector computed tomography (MDCT) contributed 35 scans and the 320-MDCT contributed 55 scans, while 12 patients were imaged using the 64-MDCT and 73 using the 320-MDCT in the split-bolus group (Table 1).

Standard scan parameters for the 64-MDCT included: voltage of 120 kilovolts (kV), automatic current modulation, thickness of 1.0 x 32 (detectors), HP (Helical pitch) 27.0 and rotation time of 0.5 seconds. Standard scan parameters used on the 320-MDCT included: voltage of 120 kV, automatic current modulation, slice thickness of 0.5 x 80, HP 65.0 and rotation time of 0.5 seconds.

The single-bolus technique entailed imaging of the urinary tract in 3 phases (non-contrast, nephrographic and excretory). A single bolus of intravenous contrast (Omnipaque 350 [Iohexol], GE Healthcare) was administered after the non-contrast phase. The dose of contrast was given at 1 ml/kg, generally falling within a volume of 65 ml to 90 ml. Following contrast injection, an injection of 30 ml of normal saline is administered via an automated power injector at a rate of 1.5 ml/s. The nephrographic phase was obtained at 90 to 100 seconds in supine position and the

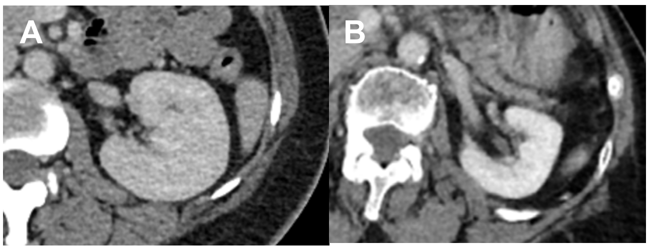

Fig. 1. An example of the difference in renal parenchymal enhancement between Tier 2 (A) and Tier 3 (B) groups on axial CT images obtained prior to contrast excretion into the pelvicalyceal system.

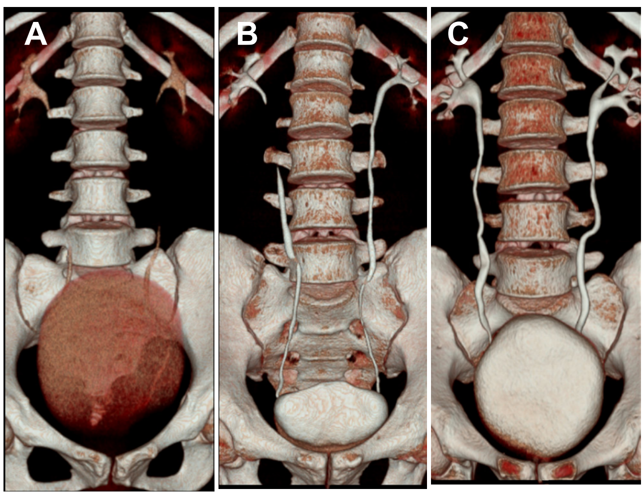

Fig. 2. An example of the differing degrees of ureteric enhancement on 3D reconstructed coronal images of the ureters, as allocated to Tier 1 (A), Tier 2 (B) and Tier 3 (C).

Table 1. The Planes Required by Each Phase for Single- and Split-Bolus CT Urography

Single-Bolus CTU Planes Acquired	Split-Bolus CTU Planes Acquired
Unenhanced phase: axial plane (3 mm thickness/3 mm reconstruction interval)	Unenhanced phase: axial and coronal planes (3 mm thickness/3 mm reconstruction interval)
Nephrographic phase: axial and coronal planes (3 mm thickness/3 mm reconstruction interval)	Combined nephrographic and excretory phase: axial and coronal planes (3 mm thickness/3 mm reconstruction interval)
Excretory phase: axial and coronal planes (3 mm thickness/3 mm reconstruction interval)	

CTU: Computed tomography urography

excretory phase was obtained at 10 minutes with the subject lying prone in order to optimise opacification of the mid and distal ureters.[13-14]

The split-bolus technique was performed using a biphasic acquisition with an unenhanced supine sequence and a single contrast-enhanced prone sequence that combined the nephrographic and excretory phases. This combined phase was achieved using 2 discrete intravenous boluses of contrast, with 45% of total dose given in the first bolus and the remaining 55% in the next bolus. The dose of contrast for this protocol was 1.5 ml/kg, with a volume ranging between 90 ml to 135 ml. For example, for a 70 kg man, the first bolus composed of 50 ml of contrast, followed by 20 ml of saline injected at a rate of 1.5 ml/s. The second bolus was administered 12 minutes later, consisting of 65 ml of contrast and 30 ml of saline at a rate of 1.5 ml/s. The result was a set of images that incorporated the nephrographic and excretory phases (Fig. 3).

Image Analysis

Images from both groups were evaluated independently by 2 experienced consultant radiologists on picture archiving and communication system (PACS) workstations.

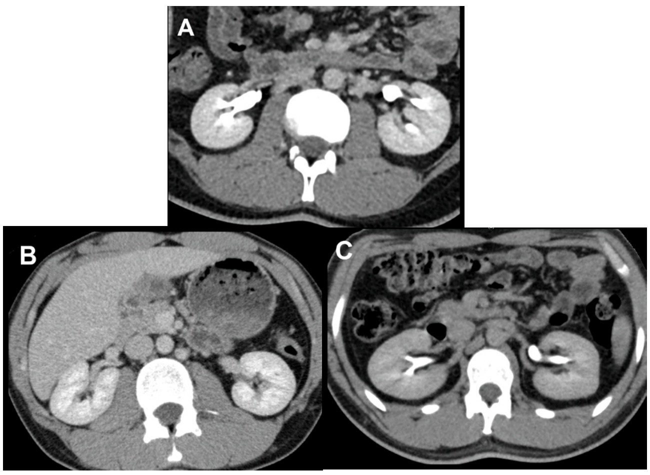

Fig. 3. How a split-bolus technique for CT urography can be utilised to produce an image (A) that incorporates the positive aspects of both the standard single-bolus nephrographic phase (B) and excretory phase (C).

For analysis, the urinary system was divided into renal parenchyma, pelvicalyceal system (calyces, infundibulum and renal pelvis), proximal ureter (from pelvi-ureteric junction to upper extent of sacroiliac joint), middle ureter (length of sacroiliac joint), distal ureter (from lower extent of sacroiliac joint to vesico-ureteric junction) and urinary bladder.

Radiation Dose Analysis

Radiation dose measurements and number of images generated for each patient were obtained from data embedded in the PACS system. Effective radiation dose (E) for all phases was calculated using E = k x dose length product (DLP), where k is a conversion unit (mSv/mGy x cm-1) and for the abdomen, it was taken as k = 0.015.

Statistical Analysis

The association between the 2 techniques and degree of opacification was assessed using Chi-squared or Fisher's exact tests, where applicable. Radiation dose was analysed using a 2 sample t-test.

Observers' agreement was measured by the weighted kappa statistic. A kappa value of 0-0.20 indicated poor agreement; 0.21-0.40 fair agreement; 0.41-0.60 moderate agreement; 0.61-0.80 good agreement; and 0.81-1.00 very good agreement.

All calculations were performed using Statistical Package for the Social Sciences (SPSS) software, version 19.0 (IBM Corp. Armonk, NY).

Results

After exclusion, there remained 90 cases within the single-bolus group (72 males, 18 females and mean age of 32.6 years, range 18 to 64 years) and 85 cases in the split-bolus group (59 males, 26 females and mean age of 32.6 years, range 17 to 41 years).

Inter-observer reliability was evaluated. The range of kappa value was found to be between 0.88 and 0.97 (Table 2), denoting very good agreement.

Opacification of the Urinary System and Evaluation of Image Quality

Enhancement of the renal parenchyma was excellent in 51% (86 of 170) of the split-bolus group and 41% (73 of 180) in the single-bolus group. No subjects from the split-bolus group were found to have poor renal parenchymal enhancement, whereas 2% (4 of 180) were considered poor in the single-bolus group (Table 3).

Table 2. The Mean Opacification Score for Each Structure Using the Single-Bolus and Split-Bolus Techniques for CT Urography, Based on the Read by Both Radiologists and the Weighted Kappa Value (a Measure of Agreement between the 2 Radiologists)

Structure	Mean Opacification Score	Mean Opacification Score	Weighted Kappa Point Estimate (95%)	Mean Score from Both Readers
Single-Bolus	**Reader 1**	**Reader 2**		
Renal parenchyma	2.4	2.4	0.865	2.4
Pelvicalyceal system	2.9	2.9	0.826	2.9
Proximal ureter	2.6	2.6	0.904	2.6
Middle ureter	2.1	2.1	0.829	2.1
Distal ureter	2.0	2.0	0.879	2.0
Urinary bladder	2.5	2.6	0.793	2.6
Split-Bolus	**Reader 1**	**Reader 2**		
Renal parenchyma	2.5	2.5	0.879	2.5
Pelvicalyceal system	2.8	2.8	0.851	2.8
Proximal ureter	2.8	2.7	0.911	2.8
Middle ureter	2.6	2.6	0.831	2.6
Distal ureter	2.5	2.4	0.807	2.5
Urinary bladder	2.6	2.7	0.816	2.7

Table 3. Individual Reader Score Comparison for Both Groups

	Reader 1 Score			Reader 2 Score		
Structure	**1**	**2**	**3**	**1**	**2**	**3**
Single-bolus						
Renal parenchyma	2 (2%)	54 (60%)	34 (38%)	2 (2%)	49 (54%)	39 (44%)
Pelvicalyceal system	0 (0%)	10 (11%)	80 (89%)	0 (0%)	9 (10%)	81 (90%)
Proximal ureter	10 (11%)	16 (18%)	64 (71%)	8 (9%)	18 (20%)	64 (71%)
Mid ureter	22 (24%)	36 (40%)	32 (36%)	19 (21%)	41 (46%)	30 (33%)
Distal ureter	31 (35%)	30 (33%)	29 (32%)	26 (29%)	35 (39%)	29 (32%)
Urinary bladder	1 (1%)	40 (44%)	49 (55%)	1 (1%)	36 (40%)	53 (59%)
Split-bolus						
Renal parenchyma	0 (0%)	45 (53%)	40 (47%)	0 (0%)	39 (46%)	46 (54%)
Pelvicalyceal system	0 (0%)	13 (15%)	72 (84%)	0 (0%)	15 (18%)	70 (82%)
Proximal ureter	3 (3%)	15 (18%)	67 (79%)	3 (3%)	16 (19%)	66 (78%)
Mid ureter	4 (5%)	29 (34%)	52 (61%)	3 (3%)	29 (34%)	53 (63%)
Distal ureter	2 (2%)	38 (45%)	45 (53%)	4 (5%)	40 (47%)	41 (48%)
Urinary bladder	0 (0%)	45 (53%)	40 (47%)	0 (0%)	29 (34%)	56 (66%)

The pelvicalyceal system was completely opacified in 84% (142 of 170) of the split-bolus group and in 89% (161 of 180) of the single-bolus group. There were no incompletely opacified portions of the pelvicalyceal system in either groups.

The proximal ureters were fully opacified/distended in 78% (133 of 170) of the split-bolus group and in 71% (128 of 180) of the single-bolus group. Incompletely opacified segments were detected in 3% (6 of 170) of the split-bolus group and in 10% (18 of 180) of the single-bolus group.

The middle ureters were entirely opacified/distended in 62% (105 of 170) of the split-bolus group but only in 34% (62 of 180) in the single-bolus group. Incompletely opacified sections were demonstrated in 4% (7 of 170) of the split-bolus group compared with 23% (41 of 180) in the single-bolus group.

The distal ureter was completely opacified/distended in 51% (86 of 170) of the split-bolus group and 32% (58 of 180) in the single-bolus group. Incompletely opacified portions were demonstrated in 4% (6 of 170) of the split-bolus group and in 32% (57 of 180) of the single-bolus group.

The urinary bladder was fully opacified/distended in 56% (90 of 170) of the split-bolus group and in 57% (102 of 180) of the single-bolus group.

There was no significant difference in opacification of the renal parenchyma and pelvicalyceal system, and opacification/distention of the proximal ureters and urinary bladder between both groups. The study showed generally higher opacification/distention scores for the middle and distal ureters in the split-bolus group, which is significant for reader 1 (Table 4).

Radiation Dose

When compared between 64-MDCT and 320-MDCT, the mean DLP was 1458.3 milli-grey per centimetre (mGy·cm) for 64-MDCT and 1229 mGy·cm for 320-MDCT in the single-bolus group. For the split-bolus group, the mean DLP was 1362.4 mGy·cm for 64-MDCT and 749.9 mGy·cm for 320-MDCT. Overall, the mean DLP was 1324.1 mGy·cm (standard deviation [SD] 687.9, range 594.0 to 3987.9 mGy·cm) for the single-bolus group, whereas the DLP for the split-bolus group was 885.7 mGy·cm (SD 595.1, range 163.2 to 2930.6 mGy·cm). The mean effective radiation dose (E) for the single-bolus group was 22.5 mSv (SD 11.7, range 10.0 to 67.8 mSV) while in the spilt-bolus group, it was 15.5 mSV (SD 10.1, range 2.8 to 49.8 mSV). The overall reduction in mean effective radiation dose between the single-bolus group and split-bolus group was 31.1%.

Number of Images

The split-bolus group produced a mean of 371 images (SD 43, range 298 to 493) whilst the single-bolus technique produced a mean of 528 images (SD 37, range 459 to 615). This equates to an average of approximately 30% fewer images for the split-bolus group compared with the single-bolus group.

Discussion

The unenhanced phase of a CT urography study is for detection of urinary calculi and provides a baseline to determine the presence of lesion enhancement in the urinary tract. The unenhanced phase is therefore considered mandatory. The nephrographic phase is when both the renal cortex and medulla are expected to be optimally enhanced while the excretory phase images allow the evaluation of the pelvicalyceal system, ureters and urinary bladder. The premise behind a split-bolus protocol is that opacification of the kidneys, pelvicalyceal system, ureters and bladders can be optimised simultaneously in 1 acquisition.

The absence of a universally standardised protocol for CT urography has given us some leeway when designing the single-bolus and split-bolus imaging protocols.[15-18]

Our CT urography protocols adhered closely to a generally accepted format. Deviations included omission of loading with intravenous fluid, abdominal compression and administration of intravenous diuretics. We did so because of the need for rapid study turnover, manpower issues and mixed opinions in the literature regarding the true benefits of these factors.[6,19] We continued to perform the excretory/combined phase in the prone position.[20-21]

Table 4. Comparison of the Proportion of Cases Achieving Full Opacification (Tier 3) in Each Group According to the Anatomical Area Under Evaluation

Structure under Evaluation	Number of Subjects with Full Opacification Ratings in the Single-Bolus Group (Total 90 [%])	Number of Subjects with Full Opacification Ratings in the Split-Bolus Group (Total 85 [%])	Significance of the Differences in the Number of Subjects Showing Full Opacification between the Groups (Expressed as *P* Values)
Reader 1			
Renal parenchyma	33 (37%)	40 (47%)	0.163
Pelvicalyceal system	80 (89%)	72 (85%)	0.413
Proximal ureter	64 (71%)	67 (79%)	0.240
Mid ureter	31 (34%)	52 (61%)	<0.001
Distal ureter	29 (32%)	48 (57%)	<0.001
Urinary bladder	49 (54%)	50 (59%)	0.559
Reader 2			
Renal parenchyma	84 (93%)	84 (99%)	0.064
Pelvicalyceal system	87 (97%)	78 (92%)	0.202
Proximal ureter	56 (62%)	56 (66%)	0.614
Mid ureter	27 (30%)	41 (68%)	0.013
Distal ureter	31 (34%)	35 (41%)	0.358
Urinary bladder	58 (57%)	57 (67%)	0.716

The patients were also mobilised before acquisition of this phase to aid mixing of opacified and non-opacified urine within the bladder. We felt this was necessary as layering of contrast would degrade the image quality and the ability to detect bladder wall lesions.[22]

Earlier papers on spilt-bolus protocols have raised concerns regarding streak artefacts from dense pelvicalyceal systems in the combined nephrographic-excretory phase, obscuring or impairing the ability to evaluate adjacent renal parenchymal lesions[4, 23] or that ureteric distension would diminish using the split-bolus technique.[7,24-25] While streak artefacts were evident in some cases in the split-bolus group, both readers concurred that none were severe enough to compromise evaluation (Fig. 4) and could be overcome through appropriate image windowing.

For our spilt-bolus protocol, a difference in timing of the excretory phase and higher amount of contrast administered were possible factors contributing to the significantly improved opacification of the middle and distal ureters in this group. We made this adjustment as earlier studies had suggest larger boluses could improve image quality.[7] The higher volume of contrast given for the second bolus may have contributed to improved distention of the ureters.

Evaluation of the radiation dose between the 2 groups showed a reduction in estimated patient dose with overall decrease in effective radiation dose of 31.1%. While differences in radiation dose reduction is affected by whether the 64-MDCT or 320-MDCT was used, both scanners demonstrated lower doses for the spilt-bolus protocol which has 1 less sequence.[26]

As anticipated, the split-bolus group boasted a 30% reduction in the mean number of images compared with the single-bolus group. The reduced image quantity offers benefits of reduced data storage requirements and a theoretical faster reporting speed.

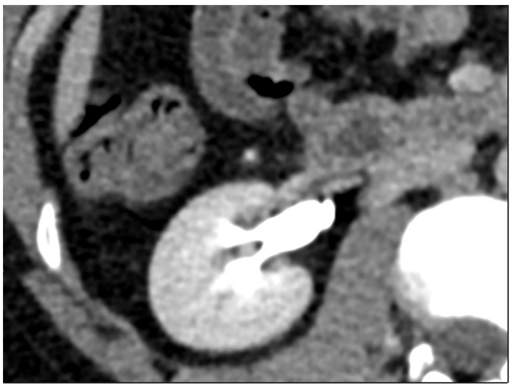

Fig. 4. An example of the degree of pelvicalyceal streak artefact detected when using the split-bolus technique.

Limitations

A double blinded format for the study was unfeasible since the image difference between both techniques would be obvious. This means that observer bias cannot be excluded.

The subjects were consecutively selected from data sets. As such, there was no subject matching between the groups. Possible confounding factors such as age, body mass index, renal function and cardiac output may alter either radiation dose, image quantity and contrast enhancement. It was hoped that the use of consecutive patients and the sample size could reduce any resultant bias.

While our study supports the opinion that image quality from a split-bolus technique is comparable to those obtained from a single-bolus technique, the diagnostic sensitivity for a lesion detected in urinary system is not directly compared. This was, however, not the aim of our study.

The 64-MDCT and 320-MDCT was used in both groups, although more patients in the split-bolus group were scanned with the 320-MDCT. This was unfortunately beyond our control given the retrospective nature of the study. Other than lower radiation dosage, the 320-MDCT confers improved temporal resolution and faster image acquisition, which is particularly advantageous for cardiac imaging.[27] However, CT urography will not require rapid scanning techniques and as such, we feel that the improvement to image quality will be minimal.

Lastly, while we feel that the image quality of the spilt-bolus technique is comparable to the single-bolus technique, appreciation of subtle enhancing lesions in the collecting system and ureters may sometimes be challenging for the split-bolus technique, given the lumens are already opacified in the postcontrast sequences. However, other signs such as mural thickening, focal calibre narrowing and upstream dilatation are usually helpful adjunct findings. Nonetheless, we continue to use a single-bolus triphasic technique for older or higher risk patients until further evidence can suggest otherwise.

Conclusion

Our split-bolus CT urography technique gives a reduced radiation dose without compromising image quality. The associated reduction in images is beneficial for data storage and reporting efficiency. As such, our department will adopt the split-bolus technique for young, low-risk patients.

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