MDCT urography: Comparison of image quality and radiation dose between single and split bolus techniques

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Aims and objectives

Introduction

Multidetector computed tomography urography (MDCTU) is recognised as the "gold standard" and first-line technique in radiologic evaluation of the kidneys and urinary collecting system pathologies; including neoplasm, infection, genitourinary trauma [1], obstructive uropathy, and urolithiasis [2]. MDCT produces not only images of high spatial and temporal resolutions but also enables isotropic or near-isotropic high quality multiplanar and three-dimensional image reconstructions [1, 3, 4]. However, a standard triphasic MDCTU protocol results in relatively high radiation doses that have been measured to be 1.5-2.0 times the dose of a standard intravenous urography [6].

Commonly, a triphasic MDCTU protocol with a single-bolus contrast injection consists of unenhanced, nephrographic and excretory phases that covers the abdomen to the pelvis [2]. This protocol is also practiced in our institution. A three-phase CT examination exposes the patients to a threefold higher radiation dose compared to a routine CT AP (abdomen and pelvis) examination. High radiation dose contributes to a stochastic effect of radiation carcinogenesis, especially in young patients.

To reduce radiation dose to the patients, a variety of MDCTU protocols and techniques have been studied. While there is no consensus to the most accurate MDCTU protocol [7], the common goal of all MDCTU techniques is to maximally distend and completely opacify the urinary tract with excreted contrast material [8-10].

Split-bolus Technique

The MDCTU split bolus technique consists of two separate contrast material bolus injections, resulting in a combined nephro-pyelographic acquisition. While the split-bolus MDCTU has led to a reduction in scan series, there is criticism that the resultant radiation dose reduction is not substantial (approximately 15%) [1]. In addition, the opacification of the kidney and the urinary tract can be diminished because a lower contrast material volume is used on the initial bolus [2]. Other technical aspects, such as time interval between the contrast material bolus injections, the volume of contrast bolus and volume of saline chaser used have also not been standardized.

Aims

1) To retrospectively compare the image quality with respect to the opacification of kidneys, urinary tracts (including pelvicalyceal system, proximal, middle and distal ureter) and urinary bladder.
2) To compare the difference in radiation doses of the single and split bolus techniques.
Methods and materials

Subjects and Study Design

The retrospective study was approved by the local centralized institutional review board (CIRB). As this was a retrospective study, patient informed consent was not required.

Between September 2012 and February 2013, 85 patients had a split-bolus MDCTU performed in our institution. A matched control group of 90 patients that had underwent a single-bolus MDCTU between March and August 2012 were randomly selected from our workload database. The inclusion criteria was a history of suspected urolithiasis. Patients above 40 years were excluded as they were thought to have a higher risk for urological malignancies.

The scan images were independently analyzed by two consultant radiologists, who were blinded to each other's given scores. The opacification of the urinary system were assessed qualitatively and quantitatively using a three-point scale:

1: Poorly opacification, insufficient for accurate diagnosis
2: Some opacification, not optimal but sufficient for diagnosis
3: Very good, intense contrast enhancement for accurate diagnosis.

Scanning protocols

For both single- and split-bolus techniques, patients drank 500mL of water 20-30 minutes prior to the examination and no diuretic was given. Two different MDCT scanners were used: 64-MDCT (35 patients underwent single-bolus technique and 12 patients underwent split-bolus technique) and 320-MDCT (55 patients underwent single-bolus technique, 72 patients underwent split-bolus technique.)

Single-bolus

The single-bolus MDCTU technique consisted of three imaging phases, with a single bolus intravenous contrast (Omnipaque 350mg/dL [iohexol]) injection using an automatic power injector. The first imaging acquisition was an unenhanced scan. This was followed by a nephrographic phase (at 90-100 seconds) obtained by administering 70mL of contrast and a 30mL of saline chaser at a rate of 1.5mL/s. The final excretory phase was obtained 10 minutes later. The volume of contrast administered was determined by the habitus of patients (ranging from 65mL to 90mL). The unenhanced and nephrographic
phases were performed in a supine position while the excretory phase was done in a prone position.

**Spilt-bolus**

The split-bolus MDCTU consisted of a biphasic acquisition series: an unenhanced phase in supine position and a single contrast-enhanced set of images (combined nephrographic and excretory phases) in prone position. This was obtained with two boluses of contrast medium injection: 50mL of contrast and 20mL of saline chaser at a rate of 2mL/s was administered right after the unenhanced phase; followed 12 minutes later by the second bolus consisting 65mL of contrast and 30mL of saline chaser at a rate of 1.5mL/s.

By splitting the contrast material into two separate bolus injections, a combined nephrographic-excretory phase was achieved as demonstrated in **figure 1**. Opacification of the urinary tract was obtained from the first bolus while the second bolus served to enhance the kidneys just prior to image acquisition.

Patient was asked to mobilise outside the scan room after the first contrast injection to allow mixing of contrast and urine in the urinary bladder. A total 115mL of intravenous contrast was administered.

The unenhanced acquisitions of both techniques and the excretory phase of single-bolus technique included the kidneys to the pubic symphysis. Meanwhile, the nephrographic acquisition of single-bolus technique and the combined nephrographic and excretory acquisition of split-bolus technique included the liver to the pubic symphysis.

**Image Analysis**

Two radiologists with six and five years of experiences respectively assessed the images independently by using axial and coronal planes on PACS (picture archiving and communication system) workstation. For purposes of this study, the organs of urinary system were divided into:

(1) Renal parenchyma

(2) Pelvicalyceal system, including calyces, infundibula, and renal pelvis

(3) Proximal ureter (from the ureteropelvic junction to iliac crest)

(4) Middle ureter (from the iliac crest to the inferior sacroiliac joint)
(5) Distal ureter (from the inferior sacroiliac joint to the ureterovesical junction)

(6) Urinary bladder.

11 patients who were found to have obstructive hydronephrosis or hydroureter were subsequently excluded in this study as these conditions were thought to affect the usual opacification of the urinary system.

**Radiation Dose Analysis**

The effective radiation dose for all the phases done in single- and split-bolus MDCTU was taken as:

\[ E = k \times DLP \]

Where \( E \) is effective dose, \( k \) is a conversion unit (mSv/mGy x cm\(^{-1}\)), and \( DLP \) is dose length product (CT dose x CT scan length in units of mGy.cm). The \( k \)-value of abdomen is 0.015.

**Statistical Analysis**

All calculations were performed using SPSS software (Statistical Package for the Social Sciences, version 19.0). Mean opacification score from each radiologist, the mean score from both radiologists, and the weighted kappa (interrater reliability) were calculated. Opacification score was analysed using Fisher's exact test. Radiation dose was analysed using two-sample t-test. The information of radiation dose and numbers of images generated from each patient were obtained from PACS workstation.
Fig. 1: A combined of nephrographic and excretory phase obtained after initial contrast bolus of 50mL and follow by 65mL of contrast at 15 minutes © "Department of Radiology, Changi General Hospital Singapore 2013.

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Results

Interrater Reliability

The kappa values of single- and split-bolus MDCTU were good, ranging from 88% to 97% agreement. *Table 1*(Single-bolus) and *Table 2*(Split-bolus) summarized the mean opacification score for each technique by both radiologists and the weighted Kappa point.

Patients

There were 90 cases (72 males, 18 females, mean age 32.6 years) for single-bolus MDCTU and 85 cases (59 males, 26 females, mean age 32.6 years) for split-bolus MDCTU.

Opacification of the Urinary System and Image Quality

Image quality of renal parenchyma in the contrast-enhanced phase was evaluated as excellent in 51% of patients for split-bolus technique and in 41% for single-bolus technique. Neither reader noted poor contrast-enhanced renal parenchyma for the split-bolus technique but 2% was deemed poor for the single bolus technique.

Complete opacification of the pelvicalyceal system was achieved in 84% of patients for the split-bolus technique compared to 90% of patients for single-bolus technique. For the proximal ureter, it was achieved in 79% for the split-bolus technique compared to 71% for the single-bolus technique. Neither readers noted unopacified segments at the pelvicalyceal system level for both techniques, while 4% of proximal ureters segments were unopacified for split-bolus technique and 10% for single-bolus technique.

The middle ureter was completely opacified in 62% of patients for split-bolus technique compared to 35% of patients for single-bolus technique. It was unopacified in 5% of patients for split-bolus technique compared to 23% of patients for single-bolus technique.

The distal ureter was completely opacified in 51% of patients for split-bolus technique compared to 32% of patients for single-bolus technique. It was unopacified in 4% of patients for split-bolus technique and in 32% of patients for single-bolus technique.

The bladder was fully opacified in 57% of patients for split-bolus technique and in 57% of patients for single-bolus technique.
Overall, between both techniques; there were no significant difference in the opacification of the renal parenchyma, pelvicalyceal system, proximal ureter, and urinary bladder. However, there were significant difference in opacification scores for the middle ureter and distal ureter. **Table 3** shows the p-value results for both radiologists when the 2 techniques are compared (p<0.05 was taken as significant). **Figure 2** compares the mean opacification scores of the urinary system for single- and split-bolus MDCTU.

**Table 4 and 5** summarized the opacification score distribution by numbers and percentages for split- and single-bolus technique MDCTU.

**Radiation Dose**

The mean CTDIvol was 65.6mGy for 64-MDCT and 27mGy for 320-MDCT in the single-bolus technique while the mean CTDIvol was 42.8mGy for 64-MDCT and 16.9mGy for 320-MDCT in the split-bolus technique.

The mean DLP was 1458.3mGy.cm for 64-MDCT and 1229mGy.cm for 320-MDCT in the single-bolus technique. Meanwhile, the mean DLP was 1362.4mGy.cm for 64-MDCT and 749.9mGy.cm for 320-MDCT in the split-bolus technique.

The mean estimated effective radiation dose for single-bolus technique was 24.8mSv (range 10.0 to 67.8mSv) for 64-MDCT and 20.9mSv (range 11.3 to 53.9mSv) for 320-MDCT, while that for split-bolus technique was 23.2mSv (range 6.9 to 49.8mSv) for 64-MDCT and 12.8mSv (range 2.77 to 45.29mSv) for 320-MDCT.

For the CTDIvol, DLP and effective dose, there were marked differences between single- and split-bolus MDCTU. Using the split-bolus technique, the mean effective dose reduction achieved for 64-MDCT was 7% while that for 320-MDCT was 39%. **Table 6** compares the effective doses of both techniques for 64- and 320-MDCT.

**Number of Images**

The planes images required by each phase for single- and split-bolus MDCTU are summarized in **Table 7**. The mean number of images generated for single-bolus technique was 528 while that for split-bolus technique was 371. This was 30% less for split-bolus MDCTU.
**Table 1**: The mean score of each structure for single-bolus technique MDCTU is based on two radiologists and weighted kappa, a measure of agreement between the two radiologists.

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Table 2: The mean score of each structure for split-bolus technique MDCTU is based on two radiologists and weighted kappa, a measure of agreement between the two radiologists.

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<table>
<thead>
<tr>
<th>Structures</th>
<th>p-value</th>
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<tr>
<td></td>
<td>Radiologist 1</td>
<td>Radiologist 2</td>
<td></td>
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<tr>
<td>Renal parenchyma</td>
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<td>p=0.160</td>
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<td>Pelvicalyceal system</td>
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<td>p=0.187</td>
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<td>p=0.338</td>
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<td>Distal ureter</td>
<td>p&lt;0.001</td>
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<tr>
<td>Bladder</td>
<td>p=0.282</td>
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Table 3: The p-value results for the urinary tract structures when the 2 techniques are compared, for both radiologists.

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Fig. 2: Vertical bar graph compares the mean opacification score of renal parenchyma (RP), pelvicalyceal system (PCS), proximal ureter (PU), middle ureter (MU), distal ureter (DU), and bladder (BL) for single- and split-bolus MDCTU.

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Table 4: The number of patient and percentage recorded in each score for both radiologists in single-bolus MDCTU.

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**Table 5:** The number of patient and percentage recorded in each score for both radiologists in split-bolus MDCTU.

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<table>
<thead>
<tr>
<th>Techniques &amp; CT scanners</th>
<th>Single-bolus MDCTU</th>
<th>Split-bolus MDCTU</th>
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<td></td>
<td>64-MDCT</td>
<td>320-MDCT</td>
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<td>CTDIvol (mGy)</td>
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<tr>
<td>DLP (mGy.cm)</td>
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<td>1229.0</td>
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<tr>
<td>Effective dose (mSv)</td>
<td>24.8</td>
<td>20.9</td>
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**Table 6:** Comparison of the CTDIvol, DLP, and effective dose of single- and split-bolus MDCTU using 64- and 320-MDCT.

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<table>
<thead>
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<th>Techniques</th>
<th>Single-bolus MDCTU</th>
<th>Split-bolus MDCTU</th>
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<td>1. Unenhanced phase - axial and coronal planes (3mm/3mm)</td>
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<td>2. Nephrographic phase – axial and coronal planes (3mm/3mm)</td>
<td>2. A combined of nephrographic and excretory phase – axial and coronal planes (3mm/3mm)</td>
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</tr>
<tr>
<td>3. Delayed phase – axial and coronal plane (3mm/3mm)</td>
<td>3. 3D image of the urinary system</td>
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<tr>
<td>4. 3D image of the urinary system</td>
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**Table 7:** The planes required by each phase for single- and split-bolus MDCTU.

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Conclusion

Comparable Image Quality

Currently, there is no standardized MDCTU technique [1, 2]. All efforts in performing MDCT compromise between the best possible image quality and a reasonably low radiation exposure [11, 12].

Single bolus MDCTU may include an unenhanced and two to three contrast-enhanced acquisitions. An unenhanced scan is to detect calculus, reveals the unenhanced appearance of any mass throughout the urinary tract and provides a baseline attenuation value to calculate enhancement of lesion and other abnormality [1]. Therefore an unenhanced scan remains mandatory for the split-bolus technique. To minimize the effective radiation dose, our unenhanced scan covers only the kidneys to the urinary bladder.

For the contrast-enhanced series, the corticomedullary phase is usually acquired at 25-80 seconds after contrast material injection, the nephrographic phase after 80-120 seconds and the excretory phase after at least five minutes [13-15]. For optimal detection and characterization, renal mass are best examined during the nephrographic phase when both the renal cortex and the medulla are enhanced (Figure 3). The excretory phase images are obtained to evaluate the urothelium [1].

Our results have shown that split-bolus MDCTU is at least as robust as the single bolus MDCTU in terms of diagnostic image quality, giving good visualization of renal parenchyma and adequate opacification of the urinary tracts. Figure 4 compares the reconstructed 3D images of the opacified kidneys and urinary tracts from both techniques.

Issues on Urinary Tract Distension and Ureter Opacification

Our results compared favourably with previous studies which used a variety of techniques to opacify the urinary system. Dillman et al. [9] compared a single bolus three-phase technique with a split-bolus two-phase technique. The former technique provided better overall urinary distension but there was no significant difference between techniques for upper tract opacification. Similar to other studies [16], our study found that the distal ureter was the least well opacified segment of the urinary tract with a mean opacification score of 2.3. This is thought to be related to the smaller calibre of this portion of the ureter [7].

A theoretical disadvantage of the split-bolus technique is that it may produce less urinary tract distension when compared with a single-bolus technique. Dillman et al. [9] showed
that the only significant differences in distension between the 2 techniques occurred at the level of the renal collecting systems and not the ureters. Another concern is that a pelvicalyceal system lesion may be obscured on the combined nephrographic-excretory phase images due to streak artefacts from the adjacent renal enhancement. This can however be avoided by obtaining the nephrographic-excretory phase at correct timings [15]. Despite the above concerns, Chow et al. [17] reported a high sensitivity (100%) and specificity (99%) for detection of urothelial tumours in the renal collecting systems and renal pelvises.

Noroozian et al. [18] reported that ureteral non-opacification is a more significant problem when the unopacified segment is not dilated and this problem is not uncommon. It usually occurs as a result of peristalsis and is generally more common in the distal ureters. Meindl et al. [13] reported that the optimum delay time between 10 and 16 minutes were favourable in the distal ureter. Washburn et al. [19] reported that urinary tract opacification can be improved using intravenous hydration and delayed acquisition timing when compared to abdominal compression.

As the initial contrast bolus was smaller (50mL) in our split-bolus technique, we thought that a longer delay time (approximately 15 minutes) was needed to obtain better distension and opacification of the renal collecting system/urinary tract. Our results have shown significantly higher opacification scores for the middle and distal ureters in the split-bolus technique when compared to the single-bolus technique which had only a 10 minutes delay.

**Compression and Positioning Techniques**

Abdominal compression techniques have been used with MDCTU in an effort to distend and opacify the upper tracts. However, the results are of mixed success. Caoili et al. [20] found that compression did not improve urinary tract visualization when compared to no compression. The use of abdominal compression is not only labour-intensive but is also contraindicated in certain patients (such as those with abdominal aortic aneurysms or acute urinary tract obstruction) [7, 9]. Caoli et al. [21] reported that a small but significant improvement of urinary tract opacification and distension when using a 250mL intravenous bolus. Conversely, Sudakoff et al. [22] found no additional benefit in urinary tract opacification with an intravenous saline bolus; while Silverman et al. [23] found that there was no additional benefit to a saline infusion when intravenous furosemide was administered. We do not apply abdominal compression, intravenous saline bolus and intravenous furosemide in our institution because of work flow issues and time constraint.

For both single- and split-bolus techniques, the purpose of using prone positioning during excretory phase imaging was to better depict the opacification of the collecting system to the distal ureter. However, more recent studies could not show any significant benefit
from prone positioning [5]. For example, Wang et al. [24] reported that supine positioning resulted in overall greater opacification of the pelvicalyceal system compared to prone positioning at CT urography.

Another problem common to both techniques is the mixing of excreted contrast and urine in the bladder with fluid-fluid (contrast-urine) levels. Homogeneous opacification may improve sensitivity in the detection of urothelial lesions, especially in the bladder [19]. Our result had shown that the mean score of split-bolus technique for bladder was slightly better though not statistically significant. This might be because more contrast (115mL) was administered compared to 70mL for single-bolus technique. To avoid layering effects in the bladder, patients were asked to mobilise outside the CT scanner room before excretory phase image acquisition. Other methods include asking patients to void before the beginning of the examination or turning the patient on the CT scanner [25].

**Reduced Image Acquisition**

The number of images generated by split-bolus technique is 30% fewer because only two sets of image acquisitions were obtained compared to three sets of image acquisitions by the single-bolus technique. Having lesser images not only facilitate faster yet accurate interpretations but also saves on image data storage requirements.

**Reduced Radiation Dose**

The split-bolus MDCTU technique was primarily developed to reduced radiation exposure by limiting the contrast phase to a single acquisition. Our results had shown that the range of radiation dose for the split-bolus technique was 10.0 to 67.8mSv for 64-MDCT and 11.3 to 53.9mSv for 320-MDCT, while that for split-bolus technique was 6.9 to 49.8mSv for 64-MDCT and 2.8 to 45.3mSv for 320-MDCT.

Overall, patients had received a lower radiation dose, with an approximately 39% decrease in estimated effective dose on the 320-MDCT, without sacrificing study quality. The difference in radiation dose between techniques is significant for younger patients and for those requiring follow-up scans for known or previous treated urinary disease. For patients with renal or urinary tract malignancy, follow-up MDCTU imaging is typically performed every 6 to 24 months over the course of several consecutive years. When appropriate, the split-bolus technique should be considered, in view of the significant reduction in patient radiation exposure.

**Limitations**

Our study had a few limitations.
Firstly, because the split-bolus combined nephrographic and excretory phase images demonstrate both renal parenchymal contrast enhancement and contrast material within the urinary tract, the radiologists could not be blinded with respect to the protocols when reviewing the images. Observer bias cannot be excluded.

Secondly, the effects of subject inhomogeneity, including factors such as patient weight, height, body mass index, renal function, and cardiac output, were not taken into account and those factors might influence the results.

Thirdly, our simple three-point opacification scoring system had limited sensitivity for nuances.

Conclusion

The diagnostic image quality of the split-bolus MDCTU is at least on par when compared with single-bolus MDCTU. For the middle and distal ureters, the mean opacification scores are significantly higher for the split-bolus technique.

The split-bolus MDCTU achieve marked radiation dose reduction, achieving approximately 39% lesser when using the 320-MDCT and generated 30% lesser images.
Fig. 3: Nephrographic phase obtained 100 seconds after intravenous contrast injection reveals uniform enhancement of renal cortex and medulla © "Department of Radiology, Changi General Hospital Singapore 2012."

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Fig. 4: A. The 3D image obtained from single-bolus MDCTU. B. The 3D image obtained from split-bolus technique. Note that the bladder is "better" enhanced in the split-bolus technique (B) when compared to the single-bolus technique (A) for these 2 cases. © "Department of Radiology, Changi General Hospital Singapore 2013."

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