Original Research Article

Single Bolus (Four Phase) Versus Split Bolus (Two Phase) CT Urography - A Comparative Evaluation

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ABSTRACT

Introduction: CT urography has largely replaced traditional IVU in imaging the urinary tract as it provides both anatomical and functional information, albeit with a relatively higher dose of radiation. This study aims to evaluate and compare the radiation dose, image quality and diagnostic yield of single bolus four phase and split bolus two phase CT urography techniques.

Material and methods: A total of 80 cases presenting with various urinary tract disorders who underwent CTU were included in our study. Patients were divided equally into two groups by random selection- Group -A (who underwent CTU using single bolus 4 phase technique) and B (using split bolus 2 phase technique). The CTU images of both groups were subsequently assessed.

Results: Image quality of CTU was assessed based on contrast enhancement of renal parenchyma and opacification of the collecting system. Adequate parenchymal enhancement was observed in 92.5% cases in corticomedullary phase and in 100% cases in in nephrographic phase of single bolus CTU studies. Adequate opacification of collecting system was seen in 88.25% and 90% of cases in excretory phase of single and split bolus techniques respectively. Enhancement of renal parenchyma and opacification of upper urinary tract in single and split bolus techniques was comparable with no significant statistical difference. Effective radiation dose, CTDIvol & total DLP for split bolus technique were found to be significantly lower (45.83%, 38.88% and 45.63% respectively) when compared to single bolus technique.

Conclusion: Split Bolus-Two phase CT urography technique is a useful modification of the existing Single Bolus-Four phase CT urography protocol as this results in significant radiation dose reduction without compromising the image quality

Keywords: Single Bolus Four Phase and Split-Bolus Two Phase CT Urography, Image Quality and Effective Radiation Dose.

INTRODUCTION

Before the advent of cross-sectional imaging, intravenous urography (IVU) was the only modality available for upper urinary tract imaging. With advances in imaging techniques, it was realized that IVU had a very low sensitivity when compared with ultrasonography (USG), computed tomography (CT) or magnetic resonance (MR) imaging in detection and characterization of urinary tract pathologies. [1,8,11,17] Application of multi-detector row CT using intravenous contrast to opacify the pelvicalyceal system ureters and the bladder has been termed **CT urography** (CTU). The concept of CT urography is attractive since both the renal parenchyma and collecting system can be evaluated with a single comprehensive examination[2,5,7]. With the availability of latest multidetector scanners that have high spatial resolution and advanced software applications CT urography has become a preferred technique for evaluation of the urinary tract. With few exceptions, most notably that of the unenhanced CT performed for acute flank pain and stone disease, most urological symptoms and conditions are now investigated with CTU.[3,4,17]

Indications for CTU continue to evolve. Conditions commonly referred for CTU include urinary calculus disease, haematuria, flank and abdominal pain, suspected renal or urothelial neoplasm, a variety of inflammatory conditions, and congenital anomalies of the kidneys and ureters.[17]

Most CTU protocols are multiphasic examinations that include non-contrast, enhanced, and delayed images.[10,12] Non-contrast images extending from the top of the kidneys through the bladder are obtained to evaluate for calculi, fat-containing lesions, parenchymal calcifications, exclusion of haemorrhagic changes and to provide baseline attenuation for assessment of lesion enhancement.[9] Most multiphasic scanning protocols include a cortico-medullary phase, nephrographic phase and an excretory phase. Corticomedullary phase images are obtained 20–70 seconds after the start of intravenous contrast material injection and provide information about the renal vasculature and perfusion. Nephrographic phase images are typically obtained 90– 180 seconds after initiation of intravenous contrast material administration. Nephrographic phase enhanced

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images are useful for the evaluation of the renal parenchyma, especially in the detection and characterization of renal neoplasms, parenchymal scarring, and renal inflammatory disease. Multiphasic enhanced CT scans tend to be more helpful in characterizing renal masses than single phase enhanced imaging. The intrarenal collecting systems and ureters are usually well distended by 8–10 minutes following intravenous contrast material injection, and their appearance both with and without external ureteral compression can be studied. Images of the collecting system obtained during the excretory phase are essential for assessing subtle urothelial abnormalities including urothelial tumours, papillary necrosis, caliceal deformity, ureteral stricture, and inflammatory changes of the renal collecting systems, ureters, and bladder.[18,19]

As an alternative to the multiphasic single bolus CTU technique, a split contrast bolus technique has been proposed whereby the contrast is given as two boluses before a single enhanced-scan is acquired.[6,15,16] The aimed cumulative effect is that the first contrast bolus provides excretory information, while the second bolus provides information on vascular anatomy and renal parenchyma.[10] The benefit of this protocol is the elimination of an additional acquisition thereby resulting in a decreased radiation dose.[5,8,13,14]

MATERIAL AND METHODS

This prospective study was conducted over the period of 18 months (from April 2019 to September 2020), following approval of institutional scientific and ethical committee. A total of 80 cases of all ages with various urinary tract disorders referred to department of Radiology for CT Urography were included in the study. Written informed consent was obtained from all patients for their inclusion in the study. Patients undergoing CTU were divided equally into two groups-A and B by random selection. Forty patients in Group A underwent Single bolus four phase CTU and the other 40 in Group B underwent Split bolus two phase CTU. Both single bolus four phase and split bolus two phase CT Urography were performed on 128 slice MDCT (Somatom Definition AS+, Seimens, Germany) Imaging was performed in supine position with breath holding at maximum inspiration. Contiguous axial sections of 2-3mm slice thickness were taken from diaphragm to the greater trochanter. Coronal and sagittal 2-3mm MPR and additional post processing MIP & 3D Volume rendered images were obtained by post processing. Parameters of 120 kV, Automatic tube current modulator, (FOV of 300.00mm, rotation of 0.5 seconds) were used. Additional evaluation by prone/delayed scanning was performed wherever indicated.

CTU techniques: In both studies patients were asked to drink approximately 500ml-1L of water 20 minutes before scanning. Scanning area covered: Diaphragm to the greater trochanter.

Single bolus four phase ct urography - (Phase I to III: Performed in supine position).

Phase I: Unenhanced phase. Following Phase I, intravenous contrast material (IOHEXOL, 300mgI/ml) 90 mL (1.2-1.5ml per Kg body weight) was administered using a pressure injector at a rate of 3 mL/s.

Phase II: Arterial phase/ Corticomedullary phase (15-20 seconds from start of contrast injection).

Phase III: Nephrographic phase (90 seconds from start of contrast injection).

Phase IV: Excretory phase (10 minutes from start of contrast injection).[19] Patient was rotated 360 degrees on table (for 3-5 rotations) to opacify the pelvicalyceal system, ureter & bladder. Finally, breath-hold images of excretory phase were acquired in prone position.

Split bolus two phase ct urography -

Phase I: Unenhanced phase (0 minute) In supine position. Intravenous contrast material (IOHEXOL, 300 mg I/ml)(1.2-1.5ml per Kg body weight) was administered as follows.

First half: 45 mL (50% of total contrast) was administered using pressure injector at a rate of 2 mL/s after the unenhanced phase (0 min).

Second half: After 9-minute delay, remaining 45 mL (50% of total contrast) was administered at 3 mL/s rate.

Phase II: Combined (Nephrographic & Excretory) phase, 90 seconds after the second contrast bolus.[17,19] Patient was rotated 360 degrees on table (for 3-5 rotations) to opacify the pelvicalyceal system, ureter & bladder. Finally, combined nephrographic and excretory phase images were acquired 90 seconds after the second contrast bolus in prone position.

Each scan was interpreted and the imaging findings recorded. CT findings were correlated with clinical features, laboratory tests, endoscopic and /or surgical findings as per the requirements of each case.

Image quality assessment: Image quality was assessed using post contrast enhancement of renal parenchyma and opacification of the collecting system in each patient. Scoring system for image quality assessment is shown in table 1.

For the purpose of image quality assessment, the urinary tract was divided into upper and lower urinary tract as is shown below in figure 1.

Radiation dose calculation: Dose length product (DLP) is the total X-ray tube output integrated throughout the entire scan, which is obtained by multiplying CTDIvol by the scan length (in centimeters). DLP is expressed in milligraycentimeters.[20] CT dose index (CTDI) (measured in mGy) is a standardized measure of radiation dose output of a CT scanner which allows the user to compare radiation output of different CT scanners. Both CTDIvol and DLP can be used for comparison of different CT protocols and scanners.[20] Effective dose (measured in Sieverts) is intended to represent the uniform whole-body equivalent dose that can result in a similar overall cancer risk as the partial-body radiation dose delivered to the subject. It is calculated as a weighted sum of each organ's dose times that organ's

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relative risk of radiation induced carcinogenesis; it is a single dose value that is used to compare the relative biologic risk resulting from different radiation dose exposures. Effective dose can be estimated by multiplying the DLP by a conversion factor on the basis of the body region scanned in a sex- and age-neutral reference patient, although these methods may not be very accurate when applied to different patients. Effective dose reflects an average population-based risk to an average individual of average size, not the actual risk to a specificpatient.[20]

Effectve radiation dose = DLP x k

(DLP- Dose length product & k -Conversion factor)

Dose parameters {as determined with automatic exposure control (AEC) system} displayed on the console of the multidetector CT scanner.

RESULTS

Out of 80 cases, forty patients in Group A (28 males & 12 females) underwent Single bolus four phase CTU and the other 40 in Group B (32 males & 8 females) underwent Split bolus two phase CTU. Age range of the patients in Group A was 12-78 years with a mean age of 47 years and in Group B was 8-84 years with a mean age of 45 years.

Evaluation of calculus disease was the major indication in both groups of patients that underwent CTU [14/40 (35%) cases in group A and 12/40 (30%) cases in group B]. Other indications included hydronephrosis in 8 (20%) & 9 (22.5%), haematuria in 7 (17.5%) & 8 (20%), congenital malformations in 3 (7.5%) & 2 (5%), suspected renal neoplasms in 2 (5%) & 3 (7.5%), suspected urinary bladder neoplasms in 2 (5%) & 3 (7.5%) cases respectively in group A and B (Table2).

CTU findings in our study were that of calculus disease in 15/40 (37.5%) cases in Group A and 12/40 (30%) cases in Group B. Other findings included infective aetiology in 5 (12.5%) & 9 (22.5%), hydronephrosis in 7 (17.5%) & 9(22.5%), renal cysts in 6 (15%) & 4 (10%), urinary bladder neoplasm in 3 (7.5%) & 5 (12.5%), renal neoplasms in 4 (10%) & 3 (7.5%), ectopic and malrotated kidney in 2 (5%) & 1 (2.5%) cases in group A and B respectively. One case of postoperative ureteric and bladder injury 1 (2.5%) was also

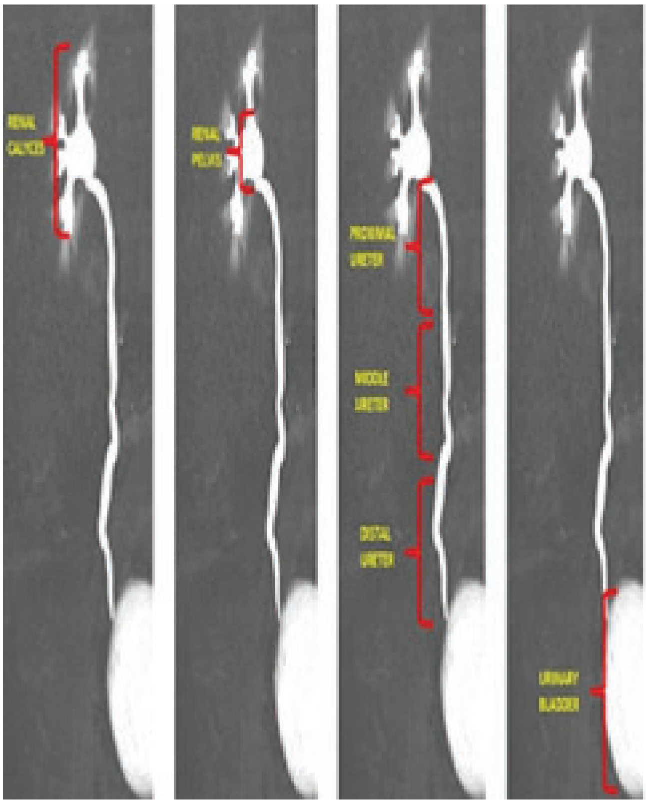

Figure-1: Division of upper and lower urinary tract for the purpose of image quality assessment.

Scoring system for image quality assessment	
0	Diagnostically inadequate enhancement or opacification
1	Diagnostically adequate enhancement or opacification

Table-1: Scoring system for image quality assessment.

	Single bolus technique	Split bolus technique
Calculus disease	14	12
Hydronephrosis	8	9
Hematuria	7	8
Infections	3	3
Congenital malformation	3	2
Suspected renal neoplasm	2	3
Suspected urinary bladder neoplasm	2	3
Suspected urinary tract injury	1	0

Table-2: Clinical indications for single and split bolus CTU.

	Single bolus technique	Split bolus technique
Calculus disease	15	12
Infections	5	9
Hydronephrosis	7	9
Renal cysts	6	4
Urinary bladder mass	3	5
Renal mass	4	3
Ectopic / malrotated kidney	2	1
Post operative ureteric/bladder injury	1	0
Normal	2	1

Table-3: CTU findings on single and split bolus CTU examinations.

	Single bolus technique	Split bolus technique
Renal calyces	93.75%	95%
Renal pelvis	91.25%	92.5%
Proximal ureter	91.25%	91.25%
Middle ureter	86.25%	88.75%
Distal ureter	78.75%	82.5%
Bladder	75%	60%

Table-4: Percentage of cases with diagnostic quality opacification of urinary tracts in excretory phase of single and split bolus CTU techniques.

	CTDIvol (mGy)	Total DLP (mGy.cm)	Effective dose (mSv)
Single bolus technique	75.11	2888	43.22
Split bolus technique	29.21	1318	19.81

Table-5: Radiation dose parameters for single and split bolus CTU techniques.

SINGLE BOLUS TECHNIQUE

Figure-2: A 32y old male with malrotated left kidney and renal pelvic calculus causing mild hydronephrosis who presented with left loin pain for 10 days. Single bolus four phase CTU. Axial (A) & coronal (B), unenhanced phase images reveal malrotated left kidney (white asterisk) with a calculus in the renal pelvis (white arrow). Axial (C) Corticomedullary and (D) nephrographic phase images show normal renal parenchymal enhancement. (E) Axial, (F) Coronal and (G) Sagittal Excretory phase images depicting left renal pelvic calculus (white arrow) and mild dilatation of the calyces. MIP (H) & VRT (I) images of same patient show faint opacification of the left ureter (white arrow).

evaluated using single bolus technique. (Table 3).

In our study 37/40 (92.5%) cases showed diagnostically adequate renal parenchymal enhancement in corticomedullary phase of single bolus technique and 40/40 (100%) cases showed diagnostically adequate parenchymal enhancement in nephrographic phases of single and split bolus techniques respectively.

Number of cases showing diagnostically adequate opacification in excretory phase for renal calyces, renal pelvis, proximal, middle, distal ureter and urinary bladder for single bolus and split bolus technique are shown in table 4.

Effective radiation dose, CTDIvol & total DLP for single and split bolus techniques were 43.22mSv, 75.11mGy &2888mGy.cm and 19.81mSv, 29.21mGy &1318mGy.cm respectively. The effective radiation dose, CTDIvol and total DLP using split bolus technique were significantly lower (45.83%, 38.88% and 45.63%) when compared with single bolus technique (Table 5).

SPLIT BOLUS TECHNIQUE

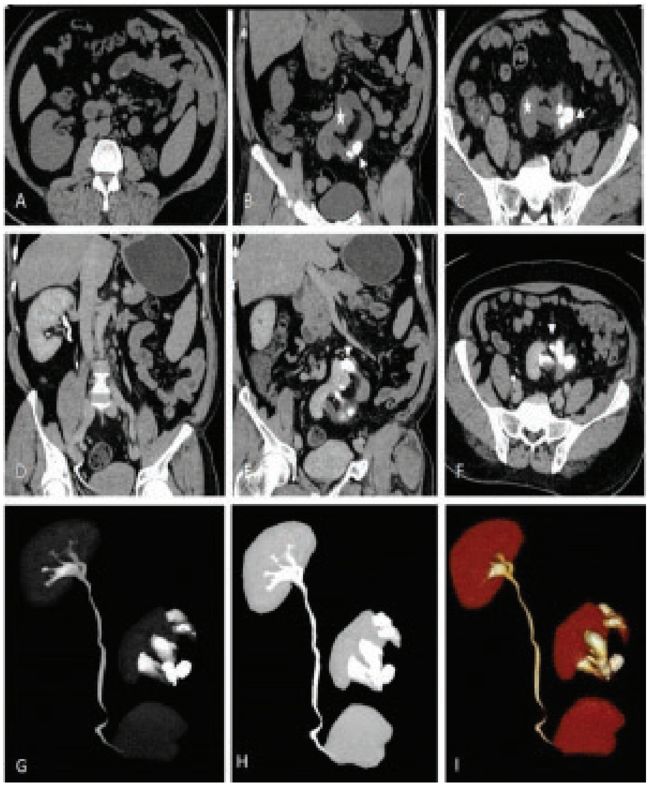

Figure-3: A 48y old male with ectopic malrotated left kidney and obstructive calculi in renal pelvis who presented with left flank pain for 1 year. Split bolus two phase CTU. Axial (A) & (C), coronal (B) unenhanced phase images showing ectopic, malrotated left kidney (white asterisk) in the left iliolumbar region with obstructive calculi (white arrow) in the pelvis. Coronal (D) & (E), Axial (F) combined phase images show moderate dilatation of the left pelvicalyceal system (white arrow) due to the obstructing calculi. MIP (G) & (H) and VRT (I) images depict non-visualization of the left ureter due to proximal obstruction.

DISCUSSION

Image quality of the CTUs performed by single and split bolus techniques in both the study groups was assessed using post contrast enhancement of renal parenchyma and opacification of the collecting system in each patient. A scoring system was used to assess the diagnostic quality of the scan as follows:

Score 0 - Diagnostically inadequate parenchymal enhancement and/or collecting system opacification.

Score 1 - Diagnostically adequate parenchymal enhancement

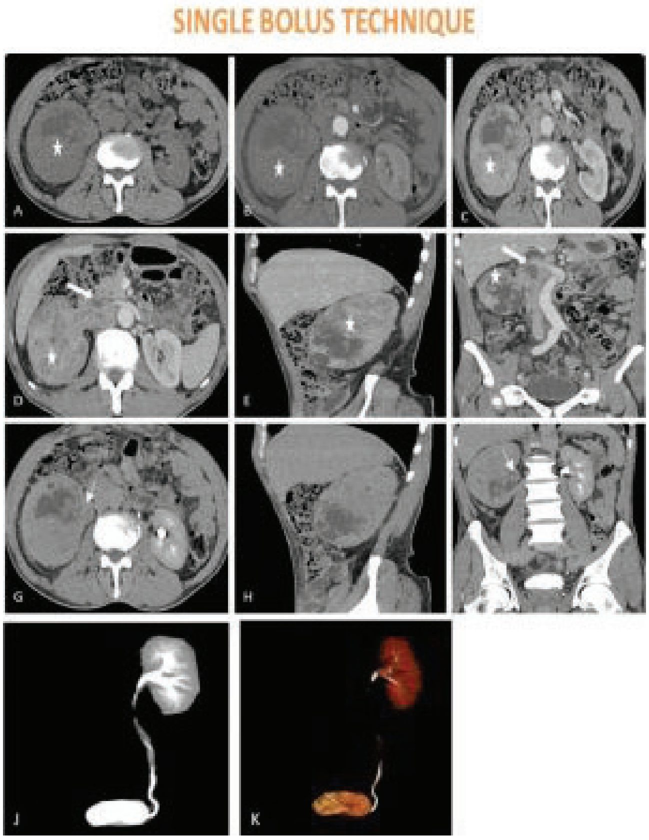

Figure-4: A 55y old male with renal cell carcinoma who presented with right loin pain for one month and found to have large mass in right kidney on sonography (not shown). Single bolus four phases CTU. (A) Unenhanced phase axial images showing a large heterogenous soft tissue density mass lesion (white asterisk) at the lower pole of right kidney. (B) Corticomedullary and (C), (D), (E) &(F) Nephrographic phase images show heterogenous enhancement of the lesion (white asterisk) with extension into the right renal vein {thick white arrow in (D)} and IVC {thick white arrow in (F)} suggestive of tumour thrombus. (G), (H) &(I) Excretory phase images show no excretion of contrast into the pelvicalyceal system (thin white arrow) due to tumour infiltration. (J) MIP and (K) VRT images of the same patient.

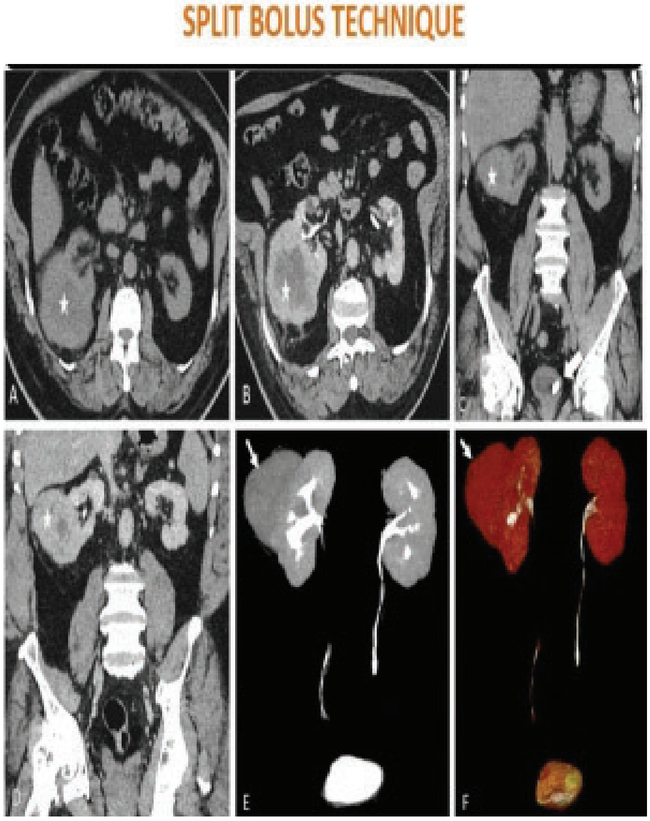

Figure-5: A 65y old male with renal cell carcinoma who presented with right loin pain and haematuria for 3 months. Split bolus two phase CTU. (A) Axial & (C) coronal unenhanced phase images show a large well defined exophytic heterogenous soft tissue density mass lesion (white asterisk) at the lower pole of right kidney and a calculus {thick white arrow in (C)} within the bladder. (B) Axial & (D) Coronal Combined nephrographic and excretory phase images showing heterogenous enhancement of the lesion (white asterisk) with central non enhancing area suggestive of necrosis. (E) MIP and F) VRT images of the same patient shows exophytic lesion at the lower pole of right kidney (thin white arrow).

and/or collecting system opacification.

In our study 37/40 (92.5%) cases showed diagnostically adequate renal parenchymal enhancement in corticomedullary phase of single bolus technique and 40/40 (100%) cases showed diagnostically adequate parenchymal enhancement in nephrographic phases of single and split bolus techniques respectively.

It is logical to assume that elimination of corticomedullary phase in split bolus two phase CTU technique may lead to suboptimal evaluation of arterial anatomy chances of missing renal artery stenosis, arteriovenous malformations / fistulas and arterial phase hyper enhancing lesions. Also, small urothelial neoplasms may be missed in the combined nephrogenic and excretory phase of because of blooming artefact in split bolus technique. It is also possible that characterization of focal renal lesion using split bolus two phase CTU may not be as good as with single bolus four phase CTU technique as early hyper enhancement and washout of the lesion may not be assessed accurately due to merging of the corticomedullary and nephrographic phases. However, we did not experience these limitations of split bolus CTU in our study as most of the renal and bladder neoplasms in our cases were large and adequately evaluated by two phase CTU.

For the purpose of image quality assessment, the urinary tract was divided into upper and lower urinary tract. Percentage of cases showing diagnostically adequate upper urinary tract opacification in excretory phase for single and split bolus techniques were 88.25% and 90% respectively and for lower urinary tract was 75% and 60% respectively. The Percentage of cases showing diagnostically adequate urinary tract opacification in excretory phase for upper urinary tract between single and split bolus techniques were comparable with no significant statistical difference in the

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two techniques. However, lower urinary tract opacification in both single and split bolus techniques were relatively less compared to upper urinary tract with significant statistical difference. This difference in the upper and lower urinary tract opacification in excretory phase in single and split bolus techniques was observed either due to relatively early acquisition of excretory or combined phase in single bolus study or upper urinary tract obstruction/ delayed excretion of contrast by the kidneys or due to dilution of contrast in urinary bladder.

Effective radiation dose, CTDIvol & total DLP for single and split bolus techniques were evaluated separately for each patient. The values of these radiation parameters in split bolus technique were significantly lower when compared with single bolus technique.

The CTU images of few cases using single and split bolus techniques are depicted in figures 2 to 5.

Limitations:

Small sample size.

Random selection of cases for the two techniques resulted in dissimilar aetiologies in the two study groups, images of which were not exactly comparable.

CONCLUSION

CT urography is a useful diagnostic tool that allows comprehensive evaluation of the urinary tract but the currently existing single bolus four phase protocol delivers high radiation dose to the patient.

Split bolus-Two phase CT urography technique is a useful modification of the existing Single Bolus-Four phase CT urography protocol as this significantly reduces the radiation dose to patients without compromising the diagnostic image quality.

The image quality of single and split bolus CTU protocols is comparable with no statistically significant difference in the diagnostic efficacy of both techniques.

We recommend the use of split bolus two phase CTU technique for most urinary tract pathologies including urolithiasis, infection and congenital anomalies. However, when evaluating focal renal lesions, small urothelial neoplasms and vascular pathologies, use of single bolus four phase study may be preferred.

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Abbreviations

MDCT - Multi-detector computed tomography; USG - Ultrasonography; CTU - Computed tomography urography; CTDIvol - Computed tomography dose index volume; MIP-Maximum intensity projection; VRT - Volume rendered tomography; IVU - Intravenous urography; DLP - Dose length product.

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