Original Article

Virtual Unenhanced Image in Abdominal Single Source Rapid Kilovoltage Switching CT Scan: Is It Comparable to True Unenhanced Image?

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Objective: To compare the attenuation values of intra-abdominal organs obtained from virtual unenhanced (VUE) images and true unenhanced (TUE) images using a single source dual-energy computed tomography (DECT) with rapid kV switching and evaluate the visibility of stones on VUE images. Radiation dose of both VUE and TUE were reported.

Materials and Methods: A retrospective cross-sectional study included 95 patients that underwent abdominal CT scan using single source DECT with rapid kV switching technique and had both TUE phase and post-contrast portovenous phase between May and November 2019. Attenuation of the abdominal organs, size, and attenuation of calyceal stones and gallstones observed on VUE and TUE were recorded. Paired t-test was calculated for comparison. Dose length product (DLP) and effective dose were also recorded.

Results: Statistically significant difference in attenuation values between VUE and TUE images were observed for liver, spleen, left adrenal gland, kidneys, aorta, inferior vena cava (IVC), main portal vein, and subcutaneous fat. No significant difference was observed for right adrenal gland (p=0.482) and paravertebral muscle (p=0.891). The mean attenuation values of the organs obtained from VUE images tended to be lower and per-case analysis showed 1.1% to 35% of cases with more than 10 HU difference. Calyceal stones and gallstones also showed smaller size and decreased attenuation on VUE images. VUE showed 75.8% and 97.4% for calyceal stones and radiopaque gallstones, respectively. By omitting TUE phase, the effective dose would be decreased by 53.2% and 53.8% for routine non-contrast and post-contrast upper abdominal and whole abdomen CT scan.

Conclusion: There were significant differences in attenuation values of abdominal organs and less sensitivity for stones detection on VUE images. Although replacing TUE with VUE could reduce radiation, some disease may be missed or misinterpreted due to erroneous attenuation values. The use of VUE may be appropriate in follow-up or with prior imaging.

Keywords: Dual energy CT, Virtual unenhanced, True unenhanced, Attenuation

Received 16 March 2020 | Revised 15 June 2020 | Accepted 23 June 2020

J Med Assoc Thai 2020;103(10):1066-74
Website: http://www.jmatonline.com

Dual-energy computed tomography (DECT) has been developed for decades with increasing utility. Material decomposition algorithms of DECT can decompose different materials into iodine, fat, soft tissue, and other predestined component such as uric acids. Various applications of the technique have been introduced, for example, liver fat quantification, artifact reduction, calcium subtraction, and virtual unenhanced (VUE) image reconstruction(1-4).

VUE images are intended to replace the true unenhanced (TUE) image to reduce scan phase, thus decrease radiation. The VUE images are generated by subtracting iodine component from contrast-enhanced images, which is a different method based on computed tomography (CT) machine vendors. Many previous studies were conducted on dual-source DECT and showed acceptable results regarding tissue attenuation and lesion conspicuity on VUE images compared to TUE images while the radiation dose was reduced by omitting the TUE scan(5-9). However, some studies differed. Sahni et al(10) found significant difference in attenuation of liver, renal parenchyma,

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How to cite this article:

Chuangsuwanich N, Pongpornsup S. Virtual Unenhanced Image in Abdominal Single Source Rapid Kilovoltage Switching CT Scan: Is It Comparable to True Unenhanced Image? J Med Assoc Thai 2020; 103:1066-74.

doi.org/10.35755/jmedassocthai.2020.10.11240

and aorta between TUE and VUE images derived from nephrographic post-contrast phase. Toepker et al[11] also reported significant difference of mean attenuation between the VUE and TUE images in many tissue types although the absolute difference was less than 10 HU. Only few prior studies on single source DECT were published. Borhani et al[12], using a single source DECT with rapid kV switching, found no significant difference in mean attenuation of many organs. In addition, the VUE images reconstructed from portovenous phase gave better correlation with TUE images as compared with the images reconstructed from arterial phase. However, intra-patient analysis showed 13% to 24% of the cases, depending on organ tissue, had attenuation difference between VUE and TUE images more than 10 HU. Although the study focused only on normal tissue, the results should still raise concern when evaluating a lesion that need precise attenuation on unenhanced image such as adrenal adenoma. Another study using single-source DECT with rapid kV switching by Mahmood et al reported 28 lesions (24.5%) not observed on VUE images, including stones or calcifications, hemorrhages, and fat lesion[13].

The present study aimed to compare the attenuation values of intra-abdominal organs obtained from VUE images and TUE images using a single source DECT with rapid kV switching and evaluate the visibility of stones on VUE images. In addition, radiation data of both VUE and TUE were reported.

Materials and Methods

The present study was a retrospective study, conducted with the approval of the Institutional Review Board (SIRB protocol No. 723/2562 IRB2). All patients underwent CT scan of upper abdomen or whole abdomen between May and November 2019. The data was extracted from the database, revealing about 700 patients. At least 93 patients were required in the present study, based on the prior study, showing mean cases with acceptable attenuation across all organs about 81% with the aimed margin error of 8.1% for 95% confidence interval (CI). Of the 700 patients, 605 patients who underwent single energy CT scan were excluded. Ninety-five consecutive patients who underwent TUE scan and post-contrast (portovenous phase) dual energy abdominal CT scan in the same session were included.

CT image acquisition

CT scans were performed using a single source DECT with rapid kV switching scanner (Discovery CT 750 HD; General Electric Healthcare, Milwaukee, Wisconsin, USA). TUE images were acquired during inspiratory breath hold using single energy mode at 120 kVp tube voltage, 80 mm beam collimation, 0.992 pitch, 0.5 second rotation time, and 250 mAs tube current-time. Non-ionic iodinate intravenous contrast (Ultravist 370; Bayer healthcare Pharmaceuticals, Wayne, NJ, USA or Iopamiro 370; Bracco, Milano, Italy) was routinely given at a dose of 2 mL/kg at a rate of 3.0 mL/second. Portovenous phases were performed during inspiratory breath hold, 80 seconds after contrast administration, using dual energy mode that rapidly switched between 80 and 140 kVp, 80 mm beam collimation, 0.992 pitch, 0.8 second rotation time, and GSI assist 230 mAs tube current-time. The TUE images were reconstructed at 5- and 1.25-mm thickness. The VUE image were reconstructed with GSI VUE software and automatically sent to picture archiving and communication system (PACS).

Image analysis

VUE and TUE data sets were reviewed using a PACS workstation (Bardo; Duluth Georgia) by a radiologist with one-year experience who was blinded from clinical information and diagnosis. VUE images were evaluated first for the presence of stones and organ attenuation values. Then, TUE images were reviewed and were considered the reference standard. Gallstones were categorized as no stone, radiolucent stone (hypodense than surrounding bile), and radiopaque stone (hyperdense than surrounding bile). Calyceal stones were categorized as no stone and radiopaque stone. If possible, size (largest diameter on axial plane) and attenuation value of the lesion were recorded. Attenuation value was measured by placing a region of interest (ROI) as large as possible within the lesion.

Attenuation values of target abdominal organs were evaluated by placing the VUE and TUE data set side by side, then same size of circular ROI (1 to 3 cm^3 as appropriate) were placed in the same location on both images. Sites and numbers on ROI were as follows: nine in liver (one in each liver segment, avoiding vascular structures and abnormal lesion, two in spleen, two in pancreas, one in each kidney, one in aorta at diaphragmatic level, one in intrahepatic inferior vena cava (IVC), one in main portal vein, one in gallbladder fluid, one in paravertebral muscle (at L1 level), and one in subcutaneous fat (at L1 level) (Figure 1). The standard deviation of attenuation measured in the subcutaneous fat was recorded as image noise. All the measurements were repeated two

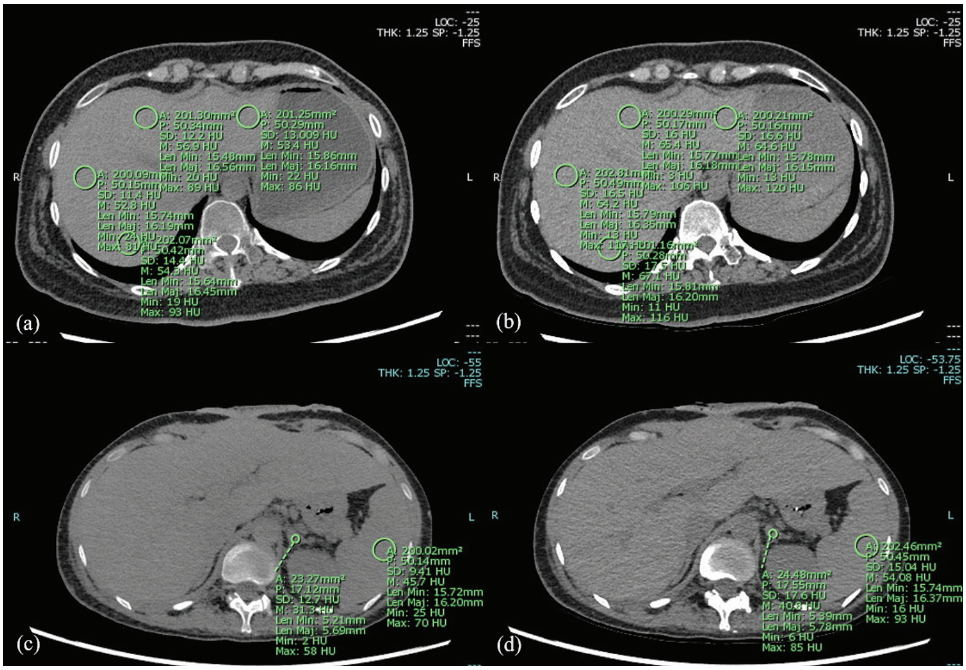

Figure 1. Example of ROI placement on VUE (a, c) and TUE images (b, d) in liver, spleen and left adrenal gland.

times at interval of two weeks apart. Mean attenuation values of the organs were calculated.

Image quality was evaluated and recorded in consensus result by two radiologists using a five-point satisfaction scale, 1=unacceptable, unable to interpret, 2=poor image quality, interfering with interpretation, 3=average image quality, interpretation possible, 4=good image quality, 5=excellent image quality (Figure 2).

The CT dose index volume (CTDIvol) and dose length product (DLP) were recorded from the dose report for TUE phase and dual-energy portovenous phase for each patient. Effective dose was calculated by multiplying DLP by conversion factor for abdomen (k-factor=0.015 $mSv \cdot mGy^{-1} \cdot cm^{-1}$)[14].

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics for Windows, version 20 (IBM Corp., Armonk, NY, USA). Mean attenuation values of each target organ and image noise from VUE and TUE images were compared using paired t-test. Size and attenuation values of gallstones and calyceal stones were compared using Wilcoxon matched pairs sign rank test. The p-value of less than 0.05 was considered statistically significant. The cases that had absolute attenuation difference between VUE and TUE images of more than 10 HU were calculated as percentage for each organ. The sensitivity of VUE images for gallstones and calyceal stones were calculated per-stone. Sensitivity and specificity were also calculated on per-patient basis patients. Patients with less stones found on VUE compared with TUE were determined as false negative and patients with any stones found on VUE image but not on TUE were determined as false positive. Satisfaction scores were described as mean and range.

Results

Of the 95 patients, there were 43 males and 52 females, with mean age of 60.6 years (range 18 to 68 years). Fifty-four patients (56.8%) underwent whole abdominal CT scan and 41 patients (43.2%) underwent upper abdominal CT scan. Three patients had undergone splenectomy, one patient had undergone left nephrectomy, one patient had undergone pancreatectomy, and 17 patients had undergone cholecystectomy.

Mean attenuation values of the organs measured on VUE and TUE images, mean differences, and the results of paired t-test are shown in Table 1. Statistically significant difference in attenuation values between VUE and TUE images were observed for liver, spleen, left adrenal gland, kidneys, aorta, IVC, main portal vein, and subcutaneous fat. No significant difference was observed for right adrenal

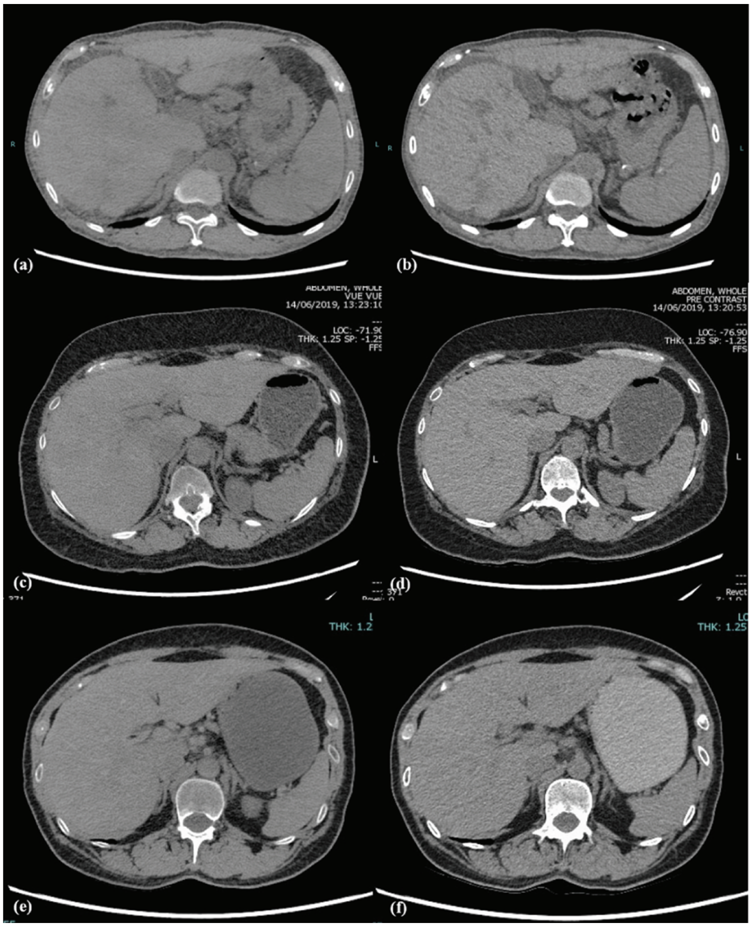

Figure 2. Example images of satisfaction scale 3-5 for VUE images (a, c, e) and TUE images (b, d, f).

Table 1. Results of paired student t-test comparing attenuation values of abdominal organs measured on VUE and TUE images

Organ	VUE HU Mean±SD	TUE HU Mean±SD	Mean difference	p-value
Liver	53.2±6.2	57.3±8.6	–4.2	<0.001
Spleen	45.1±3.4	51.0±4.4	–5.9	<0.001
Right kidney	28.5±4.8	34.1±3.4	–5.6	<0.001
Left kidney	27.8±5.2	34.0±2.9	–6.2	<0.001
Right adrenal	30.4±7.7	31.1±8.3	–0.6	0.482
Left adrenal	27.1±8.0	29.7±7.2	–2.7	0.002
Pancreas	38.5±5.1	45.3±7.5	–6.8	<0.001
Gallbladder fluid	14.0±7.5	16.2±7.7	–2.2	<0.001
Muscle	48.6±6.6	48.6±6.4	0.0	0.891
Subcutaneous fat	–100.4±16.1	–103.7±14.7	3.2	<0.001
IVC	32.2±5.2	40.6±5.4	–8.4	<0.001
Portal vein	34.8±6.8	40±5.1	–5.2	<0.001
Aorta	33.0±7.3	39.3±8.0	–6.4	<0.001

VUE=virtual unenhanced images; TUE=true unenhanced images; SD=standard deviation; HU=housefield units; IVC=inferior vena cava

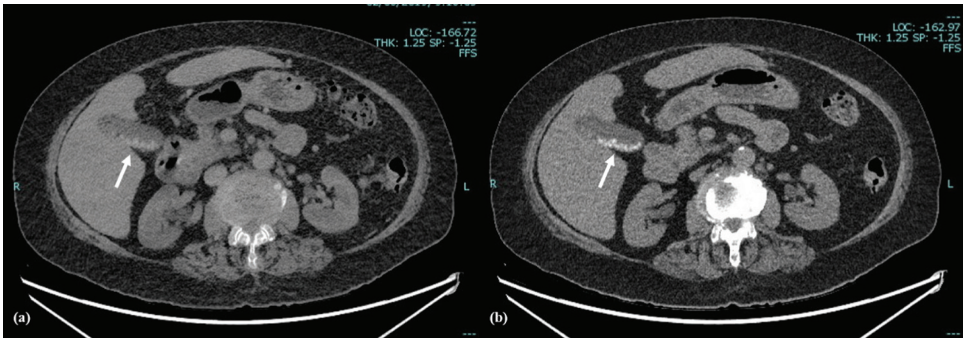

Figure 3. Example of gallstones (arrow) showing smaller and decreased density on VUE image (a) compared with TUE image (b).

Table 2. Number of cases with attenuation difference between VUE and TUE images more than 10 HU

Organ	n (%)
Liver	7/95 (7.4)
Spleen	14/92 (15.2)
Right kidney	20/95 (21.1)
Left kidney	21/94 (22.3)
Right adrenal	21/95 (22.1)
Left adrenal	23/95 (24.2)
Pancreas	22/94 (23.4)
Gallbladder fluid	3/78 (3.8)
Muscle	1/95 (1.1)
Subcutaneous fat	6/95 (6.3)
IVC	37/95 (38.9)
Portal vein	19/95 (20.0)
Aorta	34/95 (35.8)

IVC=inferior vena cava

gland (p=0.482) and paravertebral muscle (p=0.891). The mean attenuation values of the organs obtained from VUE images tended to be lower than TUE images with the maximal difference of 8.4 for IVC. Although the mean difference of attenuation was small, less than 10 HU, per-case analysis showed considerable amount of cases with more than 10 HU difference, which are liver (7.4%), paravertebral muscles (1.1%), gallbladder fluid (3.8%) and subcutaneous fat (6.3%), while other organs showed more cases (15.2% to 35.8%) with more than 10 HU difference (Table 2).

Twenty patients had radiopaque gallstones with a total of 38 opaque gallstones based on TUE images (range 1.2 to 14.2 mm). Thirty-seven (97.4%) radiopaque stones of 19 patients were observed on VUE images. Per-patient basis, sensitivity, and specificity with 95% CI were 95% (95% CI 75.13 to 99.87) and 100% (95% CI 95.20 to 100), respectively. The stone that was not visible on VUE image was 5 mm in size (82 HU) on TUE image. No radiolucent stone was found.

Sixty-six calyceal stones (range 1.4 to 26.5 mm on TUE images) of 19 patients were observed on TUE images. Fifty calyceal stones (75.8%) were detected on VUE images. The stones that were invisible on VUE image were 1.4 to 2.3 mm in size and 99 to 241 HU on TUE image. The detection rates were 25% and 85.1% for 0 to 2 mm and 2.1 to 3 mm-sized stones, respectively. Per-patient basis, sensitivity, and specificity with 95% CI were 52.63% (95% CI 28.86 to 75.55) and 100% (95% CI 95.20 to 100), respectively. Attenuation and size of the gallstones on VUE images were significantly lesser than TUE images (Z=–5.243, p=0.000 for attenuation; Z=–4.886, p=0.000 for size). Attenuation and size of the calyceal stones on VUE images were also significantly lesser than TUE images (Z=–5.411, p=0.000 for attenuation; Z=–5.464, p=0.000 for size) (Figure 3, Table 3, 4).

For image quality, mean satisfaction score of VUE images was 4±0.6 (range 3 to 5). No score of 1 or 2 were given. Image noise of VUE was lower than TUE images, as mean ± standard deviation of subcutaneous fat measured on VUE and TUE were 19.2±2.3 and 32.7±8.0, respectively (p<0.001). However, there was one case with inadequate iodine subtraction in renal collecting system (Figure 4).

CTDIvol of upper abdominal scan was 8.1±0.6 mGy for TUE and 7.2 mGy for dual-energy portovenous phase. The mean DLP was 280±48.2 and 248.9±41.3. The effective dose was 4.2±0.7 mSv and 3.7±0.6 mSv for TUE and dual-energy portovenous phase, respectively. CTDIvol of whole abdominal scan was 8.3±0.5 mGy for TUE and 7.2

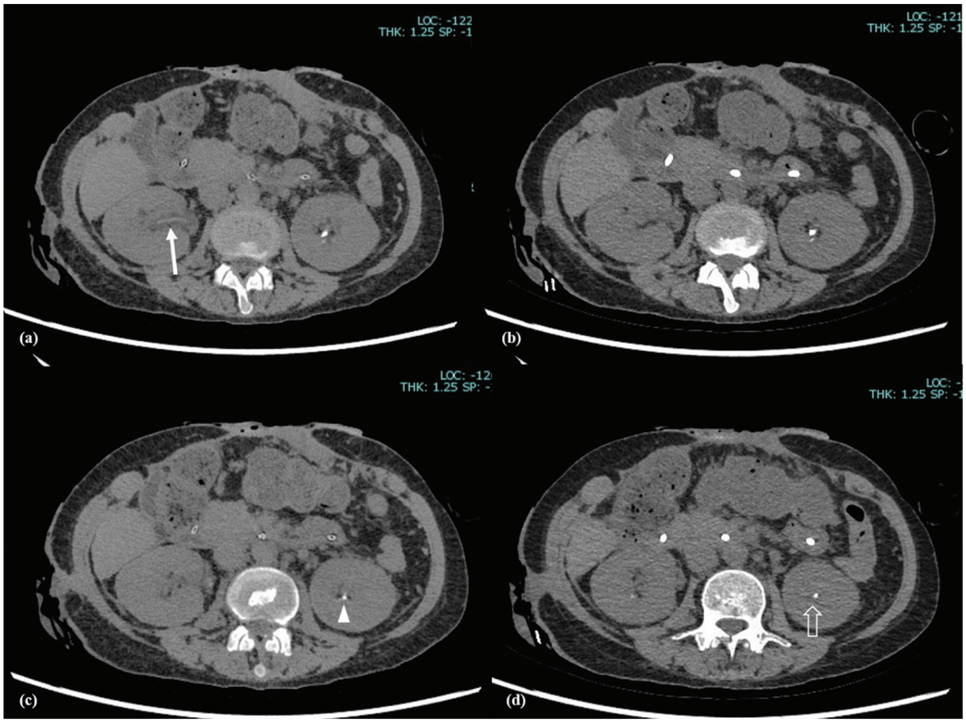

Figure 4. VUE image show inadequate iodine subtraction in right collective system on VUE image (a) (arrow) compared with TUE image (b). In addition, calyceal stones in left kidney appeared smaller in size and less attenuation on VUE image (c) (arrow head) compared with TUE image (d) (open arrow).

Table 3. Results of Wilcoxon matched pairs sign rank test comparing calyceal stones and gallstones seen on both VUE and TUE images

Stones	VUE Median (IQR)	TUE Median (IQR)	Z	p-value
Gallstones (n=37)				
Attenuation (HU)	162.0 (84.9, 261.0)	516.0 (214.5, 660.5)	–5.243	0.000
Size (mm)	5.3 (4.1, 7.9)	6.1 (4.7, 9.2)	–4.886	0.000
Calyceal stones (n=50)				
Attenuation (HU)	113.0 (89.5, 221.0)	383.0 (262.0, 604.0)	–5.411	0.000
Size (mm)	2.3 (1.8, 2.9)	2.9 (2.3, 3.9)	–5.464	0.000

VUE=virtual unenhanced images; TUE=true unenhanced images; IQR=interquartile range; HU=housefield units

Table 4. Characteristic of calyceal stones and gallstones invisible on VUE images

Gallstone (n=1)	
Attenuation (HU)	82
Size (mm)	5
Calyceal stone (n=16); mean (range)	
Attenuation (HU)	176.8 (99 to 241)
Size (mm)	1.9 (1.4 to 2.9)

VUE=virtual unenhanced images; TUE=true unenhanced images; HU=housefield units

mGy for dual-energy portovenous phase. The mean DLP was 420±46.3 and 360±36.2. The effective dose was 6.3±0.7 mSv and 5.4±0.5 mSv for TUE and dual-energy portovenous phase, respectively. By omitting TUE phase, the effective dose would be decreased by 53.2% and 53.8% for upper abdominal and whole abdomen CT scan.

Discussion

Recently, VUE CT dual energy scan have been a promising method to minimize scan phases, thus reduce the amount of radiation exposure. Many studies on dual source DECT have been published, however, due to different DECT techniques and different image reconstruction techniques from different manufacturers, the prior results may not be applicable generally. Dual source DECT uses three material decomposition method to subtract iodine, which Hounsfield can be easily measure on the image[15]. On the contrary, rapid kV switching DECT uses either two material decomposition, which the measurement will be density value or milligrams of iodine or material suppressed iodine method, replacing iodine with equal volume of blood to calculate pre-contrast Hounsfield unit value[16].

The present study, based on rapid kV switching DECT, showed significant difference between mean attenuation values obtained from VUE and TUE images in almost all organs. The results differ from prior study performed on the same type of scanner by Borhani et al[12] reported no significant difference in attenuation for liver, spleen, right kidney, both adrenal glands, aorta, IVC, portal vein, and subcutaneous fat. In the present study, organs attenuation from VUE images were lower than TUE images with more different gap observed than the previous study. Another study by Mahmood et al[13] showed no significant difference in attenuation of liver but significant higher attenuation of spleen on VUE images. The discrepancy of these results may be due to limited sample size and few studies on rapid kV switching DECT. Moreover, other factors that could contribute to lesser image quality such as body mass index (BMI), hematocrit level, and image acquisition parameters such as tube currents and tube potential, were not evaluated in the present study, However, the previous study by Borhani et al showed no significant association between attenuation and both BMI or hematocrit level[12]. These factors might need further evaluation in a larger population. Nonetheless, per-case analysis showed considerable percentage of cases that had erroneous attenuation of more than 10 HU, consistent with prior study[12]. The errors in attenuation may cause missed interpretation when evaluating enhancing lesion or fat containing lesion such as lipid rich adenoma. However, this aspect could not be evaluated due to limited cases.

For radiopaque gallstones and calyceal stones detection, the present study showed that VUE images were less sensitive for stones detection. Both gallstones and calyceal stones appeared to be smaller in size and lesser in attenuation compared with TUE images. About 75% of calyceal stones less than 2.4 mm in size were missed. Mahmood et al reported missed stones were 0.1 to 10 mm in size[13]. Other studies on dual source DECT also reported decreased sensitivity of VUE for stones less than 3.2 mm in size[10,17,18]. However, the authors found that all stones smaller than 2 mm that were visible on VUE images had more attenuation than 200 HU. Therefore, the size of calyceal stones may not be the only factor affecting stone detection. Regarding gallstone detection, due to the small number of cases, the authors only found one missed gallstone in the present study. However, previous studies on dual source DECT reported lower sensitivity of VUE for detecting gallstones sized less than 5 to 8 mm[19,20]. The missed gallstones also had significant lower attenuation compared to the visible gallstones[20]. Prior study also found that VUE may help in cholesterol gallstone detection due to the using of high and low kilovoltage[19]. Unfortunately, radiolucent gallstone was not observed in the present study.

Regarding image qualities, despite some problems about incomplete iodine subtraction in urinary tract and stones, the overall image satisfaction was good because they were no major interference with the main diagnosis. As a result, using VUE images would be benefit in cases intended for follow-up disease not related to stones or calcification to reduced radiation exposure. Further development in subtraction technique by the manufacturer may be needed in cases suspected of urinary tract disease.

The presented study had several limitations. First, the study was a retrospective and single center study. Due to small sample size, the study could not focus on specific disease or perform subgroup analysis. Second, there was only one reader evaluating stones and the reader was not blinded to the acquisition protocol. Third, small organs such as adrenal gland or small calcification may be prone to erroneous ROI measurement. Forth, the study did not consider correlation between organ attenuations and BMI or hematocrit level, however, previous study showed no correlation between these factors[12]. Fifth, the estimated radiation dose calculated in the present study was effective dose that was estimated on phantom not patient-specific dose such as organ dose.

Conclusion

The present study showed about fifty percent dose reductions for one dual phase CT scan when non-contrast phase was omitted. The overall satisfaction of VUE images were also in good range with lesser noise compared to TUE images. However, considering the variability of iodine subtraction and limitation regarding stones found, the use of VUE images instead of TUE images should not be routinely applied and should be more appropriated for follow-up cases with known diagnosis or patients with prior CT examination who do not need accurate attenuation.

What is already known on this topic?

There are few prior studies about organ attenuation obtained from VUE images using rapid kV switching DECT technique that showed no different attenuation between VUE and TUE images. However, there are some intraabdominal organs that showed more than 10 HU difference in attenuation that might interfere with the diagnosis. There are decreased sensitivity for gallstones and calyceal stones detection on VUE images, especially subcentimeter calyceal stones.

What this study adds?

There are significant differences between attenuation values obtained from VUE and TUE images of all measured organs. The attenuation values of abdominal organs, calyceal stones, and gallstones from VUE images were decreased compared to TUE images. The study also showed decreased sensitivity for stones detection on VUE images. However, the authors found that subcentimeter calyceal stones with attenuation of more than 200 HU could still be detected on VUE images. Therefore, limitation regarding stone detection on VUE images may not depend only on size, but also on attenuation of the stones, which was not reported in prior studies.

Acknowledgement

The authors would like to thank Miss Julaporn Pooliam for the statistical analyses.

Conflicts of interest

The authors declare no conflict of interest.

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