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Rapid Switching kVp Dual Energy CT: Value of Reconstructed Dual Energy CT Images and Organ Dose Assessment in Multiphasic Liver CT Exams

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Abstract

Purpose—Clinical applications of dual energy computed tomography (DECT) have been widely reported; however, the importance of the different image reconstructions and radiation organ dose remains a relevant area of investigation, particularly considering the different commercially available DECT equipment. Therefore, the purpose of this study was to assess the image reliability and compare the information content between several image reconstructions in a rapid-switching DECT (rsDECT), and assess radiation organ dose between rsDECT and conventional single-energy computed tomography (SECT) exams.

Materials and Methods—This Institutional Review Board-approved retrospective study included 98 consecutive patients who had a history of liver cancer and underwent multiphasic liver CT exams with rsDECT applied during the late arterial phase between June 2015 and December 2015. Virtual monochromatic 70 keV, material density images (MDI) iodine (-water) and virtual unenhanced (VUE) images were generated. Radiation dose analysis was performed in a subset of 44 patients who had also undergone a multiphasic SECT examination within 6 months of the rsDECT. Four board-certified abdominal radiologists reviewed 24–25 patients each, and a fifth radiologist re-evaluated all the scans to reach a consensus. The following imaging aspects were

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Dr Lorenzo Mannelli is consultant for Celgene, and a speaker for General Electric and Bracco.

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assessed by the radiologists: (a) attenuation measurements were made in the liver and spleen in VUE and true unenhanced (TUE) images; (b) subjective evaluation for lesion detection and conspicuity on MDI iodine (-water)/VUE images compared with the virtual monochromatic images/TUE images; and (c) overall image quality using a five-point Likert scale. The radiation dose analyses were evaluated in the subset of 44 patients regarding the following parameters: CTDIvol, dose length product, patient's effective diameter and organ dose using a Monte Carlo-based software, VirtualDose™ (Virtual Phantoms, Inc.) to 21 organs.

Results—On average, image noise on the TUE images was 49% higher within the liver ($p < 0.0001$) and 48% higher within the spleen ($p < 0.0001$). CT numbers for the spleen were significantly higher on VUE images ($p < 0.0001$). Twenty-eight lesions in 24/98 (24.5%) patients were not observed on the VUE images. The conspicuity of vascular anatomy was considered better on MDI iodine (-water) images 26.5% of patients. Using the Likert scale, the rsDECT image quality was considered to be satisfactory. Considering the subset of 44 patients with recent SECT, the organ dose was, on average, 37.4% less with rsDECT. As the patient's effective diameter decreased, the differences in dose between the rsDECT and SECT increased, with the total average organ dose being less by 65.1% when rsDECT was used.

Conclusion—VUE images in the population had lower image noise than TUE images; however, a few small and hyperdense findings were not characterized on VUE images. Delineation of vascular anatomy was considered better in around a quarter of patients on MDI iodine (-water) images. Finally, radiation dose, particularly organ dose, was found to be lower with rsDECT, especially in smaller patients.

Keywords

DECT; rapid-switching kV; virtual unenhanced

Introduction

Single-source, rapid-switching dual energy computed tomography (rsDECT) is emerging as a means to objectively characterize and more readily distinguish between materials and tissues based on their differential attenuation properties [1–6]. The currently available rsDECT systems use a two-material decomposition algorithm to generate a multitude of image types.

The most notable image types are material density images (MDI), which depict the density distribution for specific substances such as iodine (-water), or water (-iodine) as well as synthetic virtual monochromatic images (VMI) at different energy levels [7, 8]. The voxels within MDI water (-iodine) reconstructions represent the concentration (mg/cm^3) of water or soft tissue whereas voxels within VMI represent the more familiar Hounsfield unit (HU). Material suppressed iodine (MSI) images replace iodine content with an equal volume of blood and provide a precontrast HU value [7, 8]. The benefit of MDI water (-iodine) and MSI reconstructions is that both may be used to create virtual unenhanced (VUE) images, which may be able to replace the true unenhanced (TUE) portion of multiphasic CT scans [5, 8]. The MDI iodine (-water) reconstruction may be used to generate color coded iodine overlay maps [5], which superimpose contrast-enhanced images onto pre-contrast or VUE

images, thereby potentially improving the delineation of vascular anatomy [5]. Each post-processed image offers a unique perspective about the imaged anatomy.

Clinical applications of DECT are widely reported in abdominal imaging, particularly those related to the reduction of radiation dose and improvements in lesion detection and conspicuity [1, 9–12]. However, the dose metrics used to evaluate reductions in radiation dose from DECT typically represent dose to acrylic phantoms, not patients [13, 14]. As a result, estimates of dose reduction and any associated determination of risks may be inaccurate [14, 15]. With the growing interest in patient dose tracking and optimization of imaging protocols it is essential to have patient-specific radiation dose metrics such as organ dose [13, 14, 16]. Furthermore, the quality of each post-processed image is associated with the specific imaging task of interest, which is closely tied to the amount of radiation used to generate the image [16]. Due to the close relationship between radiation dose and image quality, an approach correlating patient-specific radiation dose with image quality, for a specific diagnostic task, will aid in the optimization and implementation of rsDECT applications [16].

The purpose of this study was therefore (a) to compare attenuation measurements and liver lesion detection on TUE and VUE, MSI and water (-iodine) images; (b) to subjectively evaluate the conspicuity of liver lesions, lymph nodes and vascular anatomy on VMI (70 keV) images and iodine overlay maps; and (c) to compare radiation organ doses between multiphasic abdominal rsDECT and single-energy computed tomography (SECT).

Materials and Methods

Study Population

The Institutional Review Board approved this Health Insurance Portability and Accountability Act-compliant single-center retrospective study; the requirement for informed consent was waived. A total of 100 consecutive patients who had history of primary or secondary liver cancer were included in this study. Each patient underwent multiphasic liver CT exams between June 2015 and December 2015. All patients were scanned with a single source, rsDECT scanner (Revolution GSI, GE Healthcare, Milwaukee, WI). Two patients were excluded because of excessive motion artifacts. The final study population was 98 patients, 63 (64%) were men. The average age of all patients was 60 years (range, 16–87). Radiation dose analysis was performed in a subset of 44 patients who had also undergone a multiphasic SECT examination (Discovery CT750 HD, GE Healthcare, Milwaukee, WI, USA) within 6 months of the rsDECT (mean age 61.4 years; range, 32–82).

Scanning Protocol

The rsDECT and SECT multiphase protocol consisted of radiographic scout images and three phases: a TUE, a late arterial, and a portal venous phase. The SECT pre-contrast and portal venous phases were identical in regard to timing of phases, tube potential of 120 kVp, helical pitch 0.984, detector coverage of 40 mm, scan rotation time of 0.7s and application of longitudinal automatic mA tube current modulation with a noise index of 14 (at a first

reconstructed slice thickness of 5 mm). In the SECT protocol, for the late arterial phase, a conventional acquisition with 120 kVp and a fixed tube current of 440 mA was used. Whereas in the rsDECT scans, gemstone spectral imaging (GSI) Assist Software (Discovery CT750 HD Technical Reference Manual, GE Medical, Milwaukee, Wisconsin, USA), which uses patient size and attenuation information derived from the scout images to suggest a rsDECT protocol, was used with a targeted noise index of 14 [8, 17, 18]. The GSI Assist suggested protocol consists of rsDECT parameters that produce a similar volume computed tomography dose index ($CTDI_{vol}$) to that of the conventional SECT [8, 17, 18].

For all exams, an automatic double-head power injector was used to administer non-ionic iodinated contrast material (Iohexol 300mgI/ml, Omnipaque 300, GE Healthcare, United States). The timing of scan initiation was determined using a bolus tracking software (SmartPrep, General Electric Medical Systems, Milwaukee, WI) with a region of interest (ROI) placed in the abdominal aorta. The contrast infusion rate was set to 150cc Omnipaque 300 at 4cc/s. A trigger threshold of 100 HU, with a 20 s delay for the late arterial phase was used for all patients.

Imaging Reconstruction

All rsDECT images were reconstructed and processed using a dedicated workstation equipped with dual energy CT) post processing software (AW 4.7, GE Healthcare, Milwaukee, WI). The rsDECT reconstructions were MSI, MDI water (-iodine) VUE reconstructions, MDI iodine (-water), iodine overlay maps and virtual monochromatic 70 keV. All images were archived to a picture archiving and communication system (PACS) for interpretation. Example images of each rsDECT reconstruction can be seen in Figure 1. The SECT images were reconstructed at 5 mm thickness and increment using the standard algorithm and with 20% adaptive statistical iterative reconstruction.

Imaging Assessment

The reading sessions were completed on a dedicated PACS workstation (Barco; Duluth, Georgia). Four board-certified abdominal radiologists with 8, 8, 24 and 27 years of experience in oncologic abdominal imaging first underwent a training session where 10 rsDECT multiphasic patient studies were reviewed in a group setting. Thereafter, each radiologist independently and randomly reviewed 24–25 patients each. A fifth board-certified radiologist with 3 years of experience in abdominal imaging reevaluated the rsDECT scans and reached a consensus with the other radiologists in all cases.

Both TUE and VUE images were both separately and simultaneously evaluated and compared regarding the two following aspects:

- a. Attenuation measurements (HU) were made in the liver and spleen by placing a 1 cm² circular ROI in a homogeneous region, avoiding vascular structures and focal lesions (Figure 2). Image noise is taken the standard deviation of HU values within the ROI. Quantitative measurements were only made on the MSI-VUE image sets.

- b. Hemorrhage, calcifications/stones and diffuse or focal liver lesions were recorded and measured in the largest diameter on the axial plane. They were also classified into 3 groups (1. Identified in both TUE and VUE, 2. Only on TUE, and 3. Only on VUE). Subjective evaluations were made on both the MSI-VUE and MDI water (-iodine) VUE reconstructions.

Furthermore, the radiologists compared the arterial phase on iodine overlay maps against the monochromatic 70 keV images regarding subjective analysis of the conspicuity of liver lesions, lymph nodes and vascular anatomy. These imaging features were classified into 3 categories according to the subjective assessment of conspicuity (1. better conspicuity on iodine maps, 2. better conspicuity on monochromatic 70 KeV and 3. equal conspicuity on both).

Finally, the radiologists used a subjective five-point Likert scale to determine the overall image quality satisfaction (1. excellent, 2. good, 3. sufficient, 4. suboptimal, 5. unsatisfactory).

Radiation Dose Analysis

For the 44 patients who had prior SECT scans, the reported $CTDI_{vol}$ and dose length product (DLP) were recorded from each patient's structured dose report. Because $CTDI_{vol}$ and DLP are not specific to patients but are standardized measures of radiation output to phantoms of a fixed size, the size-specific dose estimates (SSDE) were calculated for each patient [19].

To estimate the patient-specific organ dose, the patient age and gender, tube voltage (kVp), tube current (mA), revolution time (s), beam collimation (mm), bowtie filter type, start and end of each scan and $CTDI_{vol}$ were extracted from the DICOM data and patient records. In addition, each patient's effective diameter (ED) was calculated according to reference [19].

Organ doses were estimated using previously validated Monte Carlo-based software, VirtualDose™ (Virtual Phantoms Inc., Albany, USA). VirtualDose is commercially available and consists of a library of 25 anatomically realistic phantoms that represent pediatric, pregnant and adult patients of different ages, body morphology and sizes [20]. The 5 pairs of male and female adult phantoms covering normal weight, overweight, obese level 1, obese level 2 and morbidly obese phantoms were used in this study. Patients were matched to the appropriate phantom in VirtualDose according to their ED. The start and end of each scan was adjusted according to the scan range used in the actual patient study. The doses to 21 organs were estimated using the ICRP 103 tissue weighting factors. To reduce scanner dependency, organ doses were normalized with patient-specific $CTDI_{vol}$ values.

Because rsDECT scanners alternate between low energy (80 kVp) and high energy (140 kVp) within 0.5 ms, the reported $CTDI_{vol}$ is a combination of the X-ray output that results from both projections. For a representative determination of organ dose, the $CTDI_{vol}$ resulting from each low and high energy projection was calculated first. According to Li, et al. [21] the fraction of time that the low kVp and high kVp are enabled is 65% and 35% of the total tube revolution time, respectively. With this time distribution, the $CTDI_{vol}$ for the low kVp projection was calculated to be 30.5% of the total reported $CTDI_{vol}$. For the higher

energy projection, the $CTDI_{vol}$ was calculated to be 69.5% of the total reported $CTDI_{vol}$ [22, 23]. This relationship was validated experimentally with a 32 cm CTDI phantom.

Statistical Analysis

The continuous variables were demonstrated by using mean $\pm$ standard deviation or minimum and maximum; the categorical variables were expressed as counts and proportions. Paired t-tests were used to compare the noise levels and HU values between VUE and TUE images. A 2-sample t-test was used to evaluate the hypothesis that the mean radiation dose metrics ($CTDI_{vol}$, SSDE and Organ Dose) were similar for rsDECT and SECT examinations, versus the alternative hypothesis that these variables differ between examinations. An overall significance level of 0.05 was used for each hypothesis. The normality of the HU and noise distribution was tested using the Lilliefors normality test. All statistical analyses were performed using commercially available software (Matlab 2015, Natick, Massachusetts, USA).

Results

Imaging Assessment

Comparison of VUE with TUE—The values of image noise and CT numbers in the liver and spleen on TUE and MSI-VUE images are summarized on Table 1. On average, image noise on TUE images was 49% higher within the liver ($p < 0.0001$) and 48% higher within the spleen ($p < 0.0001$). The CT numbers for the spleen were significantly higher on MSI-VUE images ($p < 0.0001$), though they were not statistically significantly different for the liver across both TUE and MSI-VUE images ($p < 0.2853$).

All lesions detected on VUE images were seen on TUE images. However, 28 lesions in 24/98 (24.5%) patients were not observed on VUE images, including 18 (64.3%) stones/calcifications, 7 (25%) hemorrhages, and 3 (10.7%) fat lesions. Table 2 summarizes those imaging features that were not detected on VUE images and their corresponding sizes. Figure 3a–c illustrates representative cases of lesions characterized on TUE images that were not observed on VUE images.

Comparison of Iodine Overlay Maps and Monochromatic 70 KeV—The results of the subjective analysis of conspicuity of the liver lesions, lymph nodes and vascular anatomy on arterial phase between iodine overlay maps and monochromatic 70 KeV are summarized in Table 3. For most patients, conspicuity was equal on both iodine overlay maps and monochromatic 70 KeV images. Of particular interest is that conspicuity of vascular anatomy was considered better on iodine overlay maps in 26.5% of patients.

Overall image quality satisfaction—Using the Likert scale, 97% of the time the radiologists considered the imaging quality excellent, good or sufficient--none of them were considered unsatisfactory, though 3% were considered suboptimal (Table 4).

Radiation Dose Analysis

The comparison of radiation dose between the arterial phases of the rsDECT and SECT is summarized in Table 5. The total average ED was 32.05 ± 2.29 cm (range, 21.76–45.42 cm). On average, the $CTDI_{vol}$ was lower by 9.41 mGy (95% CI = 11.63–7.19), DLP was lower by 231.90 mGy-cm (95% CI = 308.16–155.70 mGy-cm), and SSDE was lower by 10.39 mGy (95% CI = 13.08–7.68 mGy) with rsDECT.

Across all patients, the spleen and liver organ dose was highest in both the rsDECT and SECT exams. The average organ doses for the spleen on SECT and rsDECT were 27.5 mGy (range, 11.7–35.5 mGy) and 17.7 mGy (range, 10.1–25.9 mGy), respectively. With regard to the liver, on SECT it was 24.3 mGy (range, 11.5–33.7 mGy) and on rsDECT it was 15.3 mGy (range, 9.71–23.8 mGy).

Across all patients and organs, the organ dose was, on average, 37.4% less with rsDECT. However, for patients with an ED 27.33 ± 2.29 cm, the total average organ dose was reduced by 65.1% with rsDECT. On the other hand, in patients with ED 29.1 ± 2.29 cm the average organ dose was reduced by only 9.77% with rsDECT.

Discussion

The results demonstrated that MSI-VUE images have lower image noise than TUE images, and the CT numbers (HU) were higher on MSI-VUE images. In some patients, imaging features containing calcium or blood were not characterized on the MSI-VUE or MDI water (-iodine) reconstructions. The reliable depiction of small calcifying, or hemorrhagic, metastases from colon, breast cancer, or melanoma in TUE scans, is useful in a small number of patients [24, 25]. The degraded image quality supports the conclusion that both MSI-VUE and MDI water (-iodine) VUE images, which are derived from the contrast enhanced portion of rsDECT, should be carefully scrutinized prior to their use as surrogates for TUE scans. However, these findings are primarily applicable to patients undergoing rsDECT scans and the diagnostic task specific to this study. In clinical settings, where missing small hyperdense lesions are not relevant for the patient workup, VUE images may be considered as adequate substitutes for TUE scans [26, 27].

Even though studies have demonstrated diagnostic improvements with rsDECT [1, 10, 28], the importance of the different image types obtained from rsDECT reconstructions remains to be clarified. In this study, conspicuity of liver lesions, lymph nodes and vascular anatomy in the arterial phase were specifically compared between monochromatic 70 keV images and iodine overlay maps. In both reconstructions we have demonstrated that liver lesions and nodes usually had similar conspicuity. The greatest difference between the two post-processing images was regarding conspicuity of vascular anatomy, where iodine overlay maps were found to be better than monochromatic 70 KeV images in over one-fourth of cases. The improved vascular anatomy delineation of iodine overlay maps may aid in mapping vessels for surgical or chemotherapy pump placement planning [29].

Although the benefits of rsDECT for abdominal oncologic applications have been reported, misconceptions about the radiation dose from two simultaneous X-ray projections and

questions regarding the accuracy of additional DECT reconstructions have limited the widespread clinical implementation of this technology [30, 31]. When comparing the radiation dose of the arterial phase between rsDECT and SECT exams, the results of this study showed that it was lower with rsDECT. The average CTDI_{vol}, DLP and SSDE were about 32.4% lower with DECT. Although these results are in accordance with previous studies [32], to our knowledge this is the first attempt to report on organ doses found on rsDECT. On average, organ doses were about 37.4% lower with rsDECT applied only during the arterial phase. The difference in radiation organ dose between the rsDECT and SECT arterial phases increased as the patient's size (as a function of ED) decreased whereas for patients of a larger size, the difference in radiation organ dose was not as large. This finding demonstrates the importance of considering patient size in any assessment of radiation dose from radiological procedures.

There are limitations in this study. First, the comparison of TUE images was only made with VUE images that had been derived from the arterial phase. Previous studies have demonstrated that arterial and portal venous VUE images are similar but lesion detection could be somewhat different between the two. Although the clinical importance of the missed lesion on VUE images or if better conspicuity of these lesions on the arterial phase images would have an impact on disease management was not specifically evaluated, the assigned overall satisfaction reflected the radiologist's opinion on diagnostic quality. This study also did not include intra-reader agreement, nor were the readers blinded to the acquisition protocol. However, each scan was read randomly. Future studies should aim to investigate the applicability of DECT protocols in a multi-institutional manner and in a blinded manner. This study also used only one attenuation/noise measurement for the liver and spleen. To improve statistics and reduce variability, multiple measurements, or multiple ROIs, within the same tissue, and averaging the results should be considered in future investigations. Regarding radiation dose, the assumptions used in calculating radiation organ dose introduced random errors. The fraction of time that each kVp is on during rapid switching will vary from patient to patient and is not constant, as assumed in this study. Furthermore, during organ dose calculations, patients were matched to a phantom in VirtualDose that had the closest ED, which could induce patient-phantom matching errors that would propagate into any calculation. Because the phantoms used in VirtualDose are rigid, patient-specific errors associated with organ position, or changes in organ size, or volume, could also impact the actual calculated organ doses. We also assumed that the dose during the pre-contrast and post-venous phase was the same for SECT and rsDECT and did not calculate the dose of these phases.

In conclusion, this study demonstrated that the MSI-VUE images have lower image noise, but if used as a substitute of TUE images, a few image findings could be missed. Conspicuity on monochromatic 70 KeV and iodine overlay maps is similar but vascular anatomy was better delineated on the latter. Overall, satisfaction of rsDECT images was excellent, good or sufficient for the majority of cases. Finally, radiation dose, particularly organ dose, was found to be lower with rsDECT, especially in smaller patients.

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Highlights

- Small, hyper attenuating lesions are not observed in virtual unenhanced scans generated from rsDECT systems.
- Iodine overlay maps are useful in delineating vascular anatomy.
- A method to calculate organ doses from rapid kVp switching DECT is proposed.
- Organ doses are lower with rsDECT, especially in smaller sized patients.

Figure 1.

Representative image types generated from the rapid-switching dual energy computed tomography (rsDECT) scan. (a) Axial, virtual monochromatic 70 keV images. (b) Material Density Image water (iodine)-Virtual Unenhanced. (c) Material Density Image iodine (-water). (d) Material Suppressed Iodine-Virtual Unenhanced. (e) Iodine map overlay.

Figure 2.

Noise measurements performed in (a) single-energy computed tomography true unenhanced (SECT-TUE) (liver noise = 9.7 HU; Spleen noise = 10.2 HU) and (b) in virtual unenhanced (VUE) (liver noise = 3.8 HU; Spleen noise = 6.8 HU). Note the small kidney stone lost on the right kidney in the VUE image. For both images, the same slice location and window were selected.

Figure 3.

From left to right: true unenhanced (TUE) images, material suppressed iodine - virtual unenhanced (MSI-VUE) images and material density image (MDI) - water (-iodine) - VUE. TUE and VUE images - MSI and MDI - water (-iodine). (a) Circled in white, VUE images did not characterize the hepatic steatosis causing the focal fat sparing to be less apparent on both MSI and MDI water (-iodine) (b) Hypoattenuating liver lesions (arrow) readily observed on TUE, but not found within the VUE images. (c) Small hemorrhagic cyst (arrow) was not seen on the VUE images. The circled object is iodine contrast inside a bowel loop.

Table 1

Noise and Computed Tomography numbers estimates for rapid-switching dual energy CT (rsDECT) Material suppressed iodine -virtual unenhanced (MSI-VUE) and single-energy CT (SECT) true unenhanced (TUE)

	Mean noise and CT Numbers (SD)		% Difference (SECT – DECT)	p-value	95% CI for Difference
	DECT VUE	SECT - TUE			
Noise:					
Liver (HU)	5.57 (3.72)	8.66 (5.23)	35.68%	<0.0001	(3.5, 4.9)
Spleen (HU)	5.32 (3.53)	8.12 (4.91)	34.48%	<0.0001	(3.3, 4.4)
CT Number:					
Liver (HU)	40.27 (24.2)	39.13 (23.9)	2.91%	<0.2853	(-4.3, 1.3)
Spleen (HU)	38.35 (22.8)	34.35 (20.6)	11.64%	<0.0001	(-6.8, -3.2)

Table 2

Imaging features not detected on both Material suppressed iodine - virtual unenhanced (MSI-VUE) and material density images (MDI) water (-iodine) VUE – per lesion

Imaging Features	Lesion size (cm $\pm$ 0.23 cm)
Stones / Calcifications (n = 18)	
Liver calcification (n = 7)	0.2–2.0
Kidney stone (n = 5)	0.1–1.0
Renal calcification (n = 3)	0.1–0.2
Aortic calcification (n = 1)	0.3
Splenic calcification (n = 1)	0.2
Gallstone (n = 1)	0.3
Hemorrhage (n = 7)	
Hemorrhagic kidney cyst (n = 3)	0.3–0.6
Hemorrhage in liver ablation zone (n = 3)	0.4–1.9
Hemorrhagic pancreatic cyst (n = 1)	0.3
Fat (n = 3)	
Hepatic steatosis (n = 3)	-

Table 3

Subjective image quality analysis between iodine overlay maps and monochromatic 70 keV images

	Better conspicuity on		
	Iodine overlay maps	Monochromatic 70 KeV	Equal
Primary liver lesion (n = 71)	2 (2.8%)	7 (9.9%)	62 (87.3%)
Lymph nodes (n = 34)	2 (5.9%)	4 (11.8%)	28 (82.3%)
Additional liver metastases (n = 12)	1 (8.3%)	1 (8.3%)	10 (83.4%)
Vascular anatomy (n = 98)	26 (26.5%)	1 (1%)	71 (72.5%)

Table 4

Radiologists' subjective overall opinion regarding image quality of dual energy computed tomography (DECT)

1 - Excellent	41 (41.8%)
2 - Good	27 (27.6%)
3 - Sufficient	27 (27.6%)
4 - Suboptimal	3 (3.0%)
5 - Unsatisfactory	0 (0.0%)

Table 5

Values of CTDIvol, Size-Specific Dose Estimates (SSDE), Dose Length Product (DLP) and Organ Doses in Dual Energy Computed Tomography (DECT) and Single-Energy Computed Tomography (SECT) examinations

	Mean Value (Range)		% Difference	p-value	95% CI for Difference
	DECT	SECT			
Arterial Phase:					
CTDIvol (mGy)	17.8 (9.05, 25.5)	27.0 (10.7, 30.4)	34.57%	< 0.0001	(-11.63, -7.19)
SSDE (mGy)	21.8 (12.7, 30.9)	32.1 (13.9, 45.6)	32.09%	< 0.0001	(-13.08, -7.68)
DLP (mGy-cm)	485.1 (191.1, 1036.7)	717.0 (268.2, 1039.8)	32.34%	< 0.0001	(-308.16, -155.70)
Organ Dose (mGy):					
Spleen	17.7 (10.1, 25.9)	27.5 (11.7, 35.5)	36.00%	< 0.0001	(-11.97, -7.64)
Liver	15.3 (9.71, 23.8)	24.3 (11.5, 33.7)	37.04%	< 0.0001	(-11.05, -7.01)
Kidneys	15.5 (9.78, 24.1)	24.5 (11.4, 32.3)	36.73%	< 0.0001	(-10.99, -7.03)
Adrenals	15.4 (8.75, 22.5)	23.8 (10.2, 30.4)	35.35%	< 0.0001	(-10.35, -6.56)
Pancreas	11.3 (6.50, 18.8)	18.5 (9.1, 27.2)	38.92%	< 0.0001	(-8.94, -5.45)
Colon	10.7 (6.22, 17.1)	17.3 (8.12, 25.7)	38.15%	< 0.0001	(-8.25, -5.05)
Stomach	9.71 (5.58, 15.7)	15.9 (7.84, 24.1)	38.93%	< 0.0001	(-7.77, -4.59)
Gall Bladder	8.76 (5.19, 14.1)	14.5 (7.39, 21.5)	39.59%	< 0.0001	(-7.03, -4.38)
Small Intestine	7.78 (4.34, 12.9)	12.9 (5.66, 20.3)	39.22%	< 0.0001	(-6.43, -3.77)
Uterus(F)/Prostate(M)	3.25 (0.37, 11.1)	6.10 (0.43, 18.2)	46.63%	< 0.0001	(-5.06, -0.64)
Lymphatic Nodes	3.74 (2.27, 6.27)	6.12 (2.95, 9.34)	38.89%	< 0.0001	(-2.97, -1.79)
Fat	3.11 (2.09, 6.01)	6.12 (2.79, 7.07)	33.82%	< 0.0001	(-2.57, -1.57)
Muscle	3.71 (2.21, 5.51)	5.78 (2.55, 7.52)	35.81%	< 0.0001	(-2.53, -1.61)
Lungs	2.82 (1.63, 4.43)	4.44 (1.90, 6.01)	36.49%	< 0.0001	(-1.99, -1.26)
Red Bone Marrow	2.55 (1.44, 4.15)	4.06 (1.68, 5.91)	37.19%	< 0.0001	(-1.87, -1.15)
Skin	2.82 (1.53, 4.19)	4.26 (1.75, 5.22)	33.80%	< 0.0001	(-1.78, -1.09)
Heart	2.08 (1.22, 3.29)	3.32 (1.43, 4.54)	37.35%	< 0.0001	(-1.51, -0.96)
Breast	1.87 (0.73, 4.41)	2.68 (0.87, 4.68)	30.22%	< 0.0001	(-1.15, -0.47)
Urinary Bladder	1.16 (0.65, 1.74)	1.82 (0.77, 2.40)	36.26%	< 0.0001	(-0.86, -0.51)
Gonads	0.79 (0.30, 1.84)	1.32 (0.33, 2.69)	40.15%	< 0.0001	(-0.79, -0.27)