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Benefit and clinical significance of retrospectively obtained spectral data with a novel detector-based spectral computed tomography - Initial experiences and results

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ABSTRACT

Objectives: To evaluate the benefits and clinical significance of retrospectively generated spectral image-datasets with the novel detector-based Spectral CT (SDCT).

Methods: A total of 118 body CTs from the SDCT prototype were included. Based on the clinical indication, two radiologists were asked if they would have opted for a dual-energy mode/scan if the patient was scanned in one of the other commercially-available dual-energy scanners, which need prospective selection of dual energy mode. They also reviewed the scans, identified cases that would benefit from spectral images and evaluated these images for clinical utility and significance on a five-point scale, with 1 being the least and 5 being the highest.

Results: Dual-energy mode would have been prospectively selected in 20 cases (17%) for Reader 1 and 25 cases (21%) for Reader 2. Additional spectral images were requested for 94 cases (80%) and 96 cases (81%) respectively. A total of 196 and 206 spectral image-sets were utilized respectively with 97% and 96% of these image-sets useful retrospectively. The distribution of scores on the five-point scale for Readers 1 and 2 were, **1**–7% & 6%; **2**–26% & 30%; **3**–36% & 36%; **4**–27% & 21% and; **5**–4% & 7%. Clinically significant score (≥ 4) was noted in 31% and 28% respectively.

Conclusions: Additional spectral datasets retrospectively reconstructed from SDCT enhanced the diagnostic capabilities by reducing artifacts, improving contrast and allowing lesion characterization.

1. Introduction

Dual-energy CT (DECT), which was first conceived in 1976, is being utilized for several clinical applications, although it is not universally adopted [1], due to cost, limited availability, lack of technical expertise, concerns about radiation, and more complex workflow and protocols. Material decomposition is performed by acquisition of datasets with two different energy spectra, and is based on the differences in attenuation of X-rays with these distinct energy spectra. The commonly used implementations of dual-energy CT are dual-source, rapid kVp switching and dual spin CT technologies [2–5]. While these technologies have certain distinct advantages and disadvantages, one common limitation of all existing technologies is that the decision to operate the scanner in the dual-energy mode needs to be made prior to the scan. Specific protocols are required for dual-energy scanning or spectral reconstructions would otherwise not be possible.

Recently, a detector-based technology, the spectral detector CT (SDCT), has been introduced for dual-energy/spectral scanning. In this scanner, there is a single X-ray source, but there is a two-layer detector. The top layer selectively absorbs low-energy photons and the bottom layer absorbs high-energy photons, thus providing two distinct energy data-sets [6]. In addition to the conventional images that are obtained by utilizing combined data from both detector layers, additional spectral analysis can be obtained by decomposition of the two "datasets", photoelectric and Compton data components of attenuation. Spectral images derived from SDCT include iodine-maps, virtual non-contrast (VNC) images, effective-atomic number (Z) images, virtual monoenergetic images (VMI) and uric acid pairs. A unique feature of this

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technology is that there is no need to prospectively screen and select patients for dual-energy mode since all the patients scanned on this scanner will have spectral information, available on demand, even in patients in whom there would have been no specific clinical indication for a dual-energy acquisition. Hence, there is no need to change the existing clinical protocol or workflow. The retrospectively generated spectral images can be used for material characterization, boosting contrast, decreasing artifacts and improving lesion detection.

In the current study, we sought to determine the proportion of routine CT scans which will need additional spectral information using the SDCT and the incremental benefit and clinical significance of these spectral images from the SDCT.

2. Materials and methods

This is a single-center IRB-approved, HIPAA-compliant study, with written informed consent obtained from all participants.

2.1. Patients

The study population included adult patients with appropriate clinical indications who were scanned on the prototype detector-based spectral CT. The exclusion criteria were: a) Age < 18 years and b) Standard exclusion criteria for CT. The study included 118 consecutive body CT (chest, abdomen and/or pelvis) patients who were scanned in the SDCT scanner between October 2013 and August 2014. One body-CT raw dataset was not archived and could not be included. The study population included 63 males and 55 females with age range of 21–90 years (60.3 ± 17.7 years).

2.2. Imaging technique

All patients were scanned in the SDCT using the standard clinical protocols for chest, abdomen and pelvis or CT angiogram. The SDCT prototype has 64 detector rows, with 0.625 mm slice thickness for a z-coverage of 4 cm and fastest gantry rotation time of 270 milliseconds. CT angiograms were obtained with ECG gating. Tube potential was set up at 120 kVp s as it allows for on-demand spectral images. The tube current (mAs) was adapted to the patient size. The protocols were dose neutral compared to our conventional CT scanner (i.e CTDIvol were matched).

2.3. Data analysis

Data analysis was performed by two independent radiologists who were fellowship trained in body imaging, with 16 and 11 years' experience in radiology, respectively. Based on the clinical indication in the requisition, the two radiologists were asked independently if they would have opted for a dual-energy scan had the patient been scanned on another commercially available dual-energy scanner which needs prospective selection of the dual energy mode, since these scanners can be operated either in single or dual energy modes. Subsequently, they reviewed the conventional CT images from the SDCT independently, blinded to each other and selected the cases which would benefit from having spectral images. These spectral images were then generated on a dedicated workstation (Spectral Diagnostic Suite, Philips, Cleveland, USA). These included VNC, iodine-map, VMI (from 40 to 200 keV), effective -Z and uric acid pairs. The clinical utility of the spectral images in improving the diagnostic capability was evaluated and the clinical significance of the individual spectral image sets was graded on a 5-point scale: 1- very low significance; 2- low significance; 3- intermediate significance; 4- moderate significance; and 5- high significance. Scores of 3 and above were considered to be clinically useful. Scores of 4 and 5 were considered to be clinically significant, i.e. they made an impact on the final diagnosis. For example, decrease in artifacts was given a score of 1 if the change was minimal and 2 if it was mild, but still made no clinical impact. Decrease in artifact which made visualization of an underlying abnormality better was given a score of 3. Lesion detection improvement by enhanced soft tissue contrast resolution was given a score of 4. Salvaging a suboptimal vascular study by improvement of vascular contrast or characterization of an incidentally encountered lesion were given a score of 5.

2.4. Statistical analysis

Statistical analysis was performed on SPSS (IBM, version 21.0, USA). Weighted Kappa scores were used to evaluate the agreement between the readers for prospective indication of DECT, the need for spectral information and the number of spectral image sets. A p value of < 0.05 was considered statistically significant.

3. Results

Of the 118 cases, there were 11 cases of CT Chest, 42 cases of CT abdomen, 10 cases of chest, abdomen and pelvis and 55 cases of CT angiography. Ninety-eight cases were performed with intravenous contrast and 10 cases were performed without intravenous contrast. This included 5 CTs of chest and 5 CT of the abdomen.

Based on the clinical indications, Reader 1 would have prospectively opted for a dual-energy mode in 20 cases (17%) but not in 98 cases (83%). The cases for which DECT mode was opted were: renal stone characterization- 3; multiphasic studies - 17 (liver-4; renal-10; pancreas 3). Reader 2 would have been prospectively opted for dual-energy mode in 25 cases (21%), but not in 93 cases (79%). The cases which would have been selected for DECT mode were: renal stone characterization - 3; multiphasic studies - 17 (liver - 4, renal - 10, pancreas - 3); and pulmonary embolism - 5 cases. There was very good agreement between readers in deciding which cases who would have been prospectively selected for DECT, with weighted kappa score of 0.86 (95% CI, 0.75–0.98).

Following review of the conventional images, Reader 1 desired retrospective spectral image sets in 94 cases (80%), and did not need them in 24 cases (20%). Reader 2 chose additional retrospective spectral image sets in 96 cases (81%) and did not need them in 22 cases (19%). There was moderate agreement between the readers for this parameter, with weighted kappa score of 0.73 (95% CI, 0.57–0.89).

Reader 1 generated 196 spectral image sets in total for 94 cases, an average of 1.6 image sets/case. Of these 196 image-sets low keV VMI were 18 (9% of image-sets), high keV VMI were 68 (35%), VNC were 37 (19%), iodine map were 54 (28%), effective-Z were 11 (6%) and uric acid pair were 8 (4%). In some cases, multiple spectral image sets were generated in the same case. Hence in terms of cases, low keV VMI was used in 16 of cases (14% of cases); high keV VMI in 53 cases (45%), VNC in 27 cases (23%), iodine-map in 45 cases (38%), effective-Z in 11 cases (9%) and uric acid pairs in 8 cases (4%) (Table 1).

Reader 2 utilized 206 spectral image sets in total for 96 cases, for an average of 1.7 image sets/case. Of these, low keV VMI was used for improving contrast in 38 (18% of image-sets) and for improving lesion visualization in 23 (11%), high keV VMI was used in 54 (26%), VNC was used in 34 (16%), iodine map in 36 (17%), effective-Z in 10 (48%), uric acid pairs in 9 (4%) and spectral attenuation curve in 2 (1%) (Table 1). In term of cases, low keV VMI for improving contrast was used in 35 cases (30% of cases), low keV VMI for improving lesion visualization was used in 18 cases (15%), high keV VMI was used in 47 cases (40%), VNC was used in 28 cases (24%), iodine map was used in 34 cases (29%), effective-Z was used in 10 cases (8%), uric acid pair was used in 9 cases (8%), and spectral attenuation curve in 2 cases (2%) cases, respectively (Table 1). Weighted kappa score between the readers was 0.49 (95% CI, 0.39–0.59).

For Reader 1, 190 (97%) of the spectral image sets were helpful, whereas 6 image sets were not helpful (3%). However, the clinical significance of these spectral images that were deemed to be helpful