Silicon strip (Si-strip) photon counting detectors (PCDs) entering use in mammography provide advantages of reduced electronic noise and dose, spectral imaging, and coincidence detection for reduction of charge sharing. We present a new implementation of PCDs configured for CT, investigate the design and 3D reconstruction algorithms to address sparse detector coverage, and evaluate performance in single and dual-energy (DE) CT.

**METHOD AND MATERIALS**

The PCD was a 5x25 cm² Philips MicroDose Si-strip detector, consisting of a 21-row sensor array at 50 µm pixel pitch (~100,000 pixels) in a sparse matrix with inter-sensor gaps up to 5 mm matched to pre-patient collimation. A benchtop CT system was configured with source-detector distance ~65 cm. Imaging was performed at 70 kVp (+0.2 mm Cu, +2 mm Al) at 0.06-0.12 mAs per frame. To overcome effects of sparse sampling, translate-rotate orbits were studied, ranging from single axial scan (1x360°) to six axially staggered scans (6x360°). Penalized-likelihood (PL) reconstruction was employed to address the complex sampling of the system through the built-in forward model and to provide noise reduction in DE decomposition through Total Variation (TV) regularization. Reconstruction-based DE decomposition of an ~8 cm diameter water phantom with inserts of iodine (10 mg/mL), calcium (200 mg/mL), and oil was performed from data collected in two energy windows.

**RESULTS**

The fraction of voxels sampled by less than one ray decreased from 65% for the 1x360° orbit to 18% for the 6x360° orbit for an 80x80x15 mm³ volume, with corresponding reduction in artifacts. DE CT images with TV regularization exhibited accurate decomposition with only slight variation with exposure; the fraction of correctly identified iodine voxels (true-positive fraction) increased from 73% to 77% and 83% for exposures of 0.06 mAs/frame, 0.09 mAs/frame and 0.12 mAs/frame, respectively; the false-positive fraction for iodine decreased from 5% and 0.06 mAs to 3% at 0.12 mAs.

**CONCLUSION**

The feasibility of volumetric CT with Si-strip PCDs in both single- and DE modes was established, demonstrating accurate DE classification of iodine and calcium in a single scan.

**CLINICAL RELEVANCE/APPLICATION**

High-performance PCDs translated to a benchtop CT platform enables single- and DE imaging from a single kVp scan and permits investigation of benefits in CT image quality, dose, and new applications.
Studies have suggested the possibility to differentiate a malignant lesion from benign tissue by characterizing them according to their water, lipid and protein composition. The purpose of this study is to investigate the feasibility of a three-material compositional measurement of water, lipid and protein content of breast tissue with dual kVp cone-beam CT.

**METHOD AND MATERIALS**

40 postmortem breasts were imaged with a flat-panel based dual kVp cone-beam CT system at 50 and 120 kVp, followed by image-based tissue decomposition into water, lipid and protein contents. The mean glandular dose (MGD) from the dual kVp scans was approximately 6 mGy. The optimal imaging protocols, in terms of dual kVp tube voltages and dose distributions were first simulated with an analytical model which maximized the dual energy signal-to-noise ratio (SNR) with respect to MGD. A three-material phantom, consisting of water, vegetable oil and polyoxymethylene plastic was used for dual energy calibration for water, lipid and protein, respectively. The expected errors due to the calibration materials were also estimated by simulation. The breasts were then chemically decomposed into their respective water, lipid and protein contents after imaging to allow direct comparison with data from dual energy decomposition.

**RESULTS**

The dual energy breast tissue decomposition in terms of the volumetric percentages of water, lipid and protein contents exhibited strong correlation with data from the chemical analysis, which is considered to be the gold standard. As compared with the chemical analysis, the average root-mean-square (RMS) percentage error in tissue decomposition for all 40 breasts was calculated to be 3.6%.

**CONCLUSION**

The results of this study suggest that the water, lipid, and protein contents can be accurately measured using dual energy breast CT. The tissue compositional information can potentially improve the sensitivity and specificity for breast cancer diagnosis.

**CLINICAL RELEVANCE/APPLICATION**

Accurate compositional analysis of breast tissue may potentially improve the sensitivity and specificity of breast cancer detection and reduce the number of biopsies needed for suspicious lesions.

SSG14-03 • Clinical Dual Energy CT (DECT): Can Monoenergetic Imaging Remove Metal Artifacts?

**PURPOSE**

DECT provides so-called monoenergetic images based on a linear combination of the original polychromatic images. At certain patient-specific energy levels $E\approx 130$ keV, corresponding to certain linear combination weights $w\approx 1.6$, a significant reduction of metal artifacts is observed. We aim at analyzing the method to identify its limitations.

**METHOD AND MATERIALS**

DECT can be used to exactly calculate virtual monochromatic images (neglecting scatter). This calculation has to be done in rawdata domain before image reconstruction. Clinical CT, however, uses a simplified version of monochromatic imaging by linearly combining the low and the high kV images, and by assigning a keV-value to that linear combination. Those pseudo monochromatic images are used by radiologists to obtain images with reduced metal artifacts. We analyzed the underlying physics and carried out a series expansion of the polychromatic attenuation equations. The resulting non-linear terms are responsible for the artifacts, but they are not linearly related between the low and the high kV scan: A linear combination of both images cannot eliminate the non-linearities, it can only reduce their impact. Scattered radiation yields additional non-cancelling non-linearities. To quantify the artifact reduction potential of pseudo monochromatic images we
simulated the Forbild abdomen phantom with metal implants and we measured a semi anthropomorphic abdomen phantom with inserts of high iodine concentration using a clinical dual source CT system (100 kV, 140 kV Sn). In each case we manually selected an optimal \( w \), and we automatically computed an optimal \( w \) by minimizing the standard deviation \( S \) of the voxel values of the smoothed (to minimize the impact of image noise) soft-tissue regions around the metal implants.

RESULTS
For the initial images \( S=150 \text{ HU} \) (100 kV) and \( 59 \text{ HU} \) (140 kV Sn). The manually setting yields \( w=1.62 \) with \( S=18.2 \text{ HU} \), while the automatic setting yields \( w=1.60 \) and \( S=18.1 \text{ HU} \). A complete artifact reduction corresponding to \( S=3.71 \text{ HU} \) (image noise only), as achieved with rawdata-based processing, was not possible with pseudo monochromatic imaging.

CONCLUSION
Pseudo monochromatic imaging is able to reduce metal artifacts (at the cost of contrast-to-noise ratio) but it cannot remove them.

CLINICAL RELEVANCE/APPLICATION
Artifact reduction through pseudo monochromatic imaging is helpful. But it should be avoided if alternative dedicated artifact reduction approaches are available.

SSG14-04 • Effectiveness of Synthesized Monochromatic Imaging Generated with a Fast Kilovoltage Switching Dual Energy CT Scanner for Improved Patient-to-Patient Uniformity of Aortic Enhancement during Abdominal CT Angiography: An In-Vivo and In-Vitro Study
Ghaneh Fananapazir MD (Presenter) ; Rendon C Nelson MD * ; Joshua Wilson PhD ; Kingshuk Choudhury PhD ; Daniele Marin MD

PURPOSE
To investigate whether virtual monochromatic imaging (VMI) generated from a fast kilovoltage-switching single-source dual-energy CT (DECT) acquisition may correct for beam hardening artifacts, improving uniformity of abdominal aortic enhancement across different body sizes.

METHOD AND MATERIALS
A proprietary tapered hollow phantom with a bone-mimicking insert and a hollow tube mimicking the aorta was developed. The tube was filled with different iodine solutions simulating various degrees of aortic enhancement. The phantom was filled with water. Single-source DECT was performed and VMIs were synthesized at different energies (40-140keV, @ 20keV increments). The phantom was also scanned using conventional polychromatic kV settings (80-140kVp, @ 20kV increments). CT numbers in the aorta and water (noise) were measured along the entire length of the phantom. 62 consecutive patients (38 M; mean age 60 years ± 13 SD; mean BMI 30kg/m2 ± 6 SD) underwent DECT scans. Aortic attenuation was measured at polychromatic 140kVp and VMI 80keV datasets. The relationship between aortic attenuation and signal-to-noise (SNR) as a function of body diameter was assessed for the phantom and clinical patients.

RESULTS
There was a significant negative correlation between both aortic attenuation/SNR and phantom diameter using polychromatic energy beams (-15.7HU/cm @ 80kVp to -6.8HU/cm at 140kVp) or VMI at energies equal or lower than 60keV (-18.7HU/cm @ 60keV to -53.5HU/cm @ 40keV). Aortic attenuation and SNR were nearly independent of phantom diameter at 80keV VMI (-4.3HU/cm; P

CONCLUSION
The 80keV VMI improved consistency of aortic enhancement across different body sizes, although this could come at the cost of decreased magnitude in aortic enhancement.

CLINICAL RELEVANCE/APPLICATION
Lower susceptibility to beam-hardening effects using VMI increases consistency in aortic attenuation measurements across different patient body sizes.
PURPOSE
We present a fast, noise-efficient, and accurate targeted least squares estimator (TLSE) for material separation using PCXDs with multiple energy bin capability. The proposed estimator uses a novel method of incorporating dynamic weighting that allows noise to be homogenous and close to the Cramer-Rao Lower Bound (CRLB) throughout the operating range.

METHOD AND MATERIALS
The TLSE estimator uses a non-iterative and adaptive least squares method followed by bias correction based on a calibration phantom. In the initial step, a generalized weighted least squares linearized at the center of the operating region is used. The second step utilizes the output from the first estimate as a pointer to localize a region in a 4-by-4 grid of operating range to extract noise-weighting statistics. This dynamically adjusts the weights of the energy bins to optimize noise properties. After this adaptive step, a localized least squares and error correction process akin to A-table method (Alvarez et al) is applied to produce the final estimate. The variance and bias of this estimator between 0 to 6 cm of aluminum and 0 to 50 cm of water is simulated with Monte Carlo methods and compared to alternative estimators.

RESULTS
The proposed estimator produced an average bias of $(2.59 \pm 4.66) \times 10^{-5}$ cm and variance-to-CRLB ratio of $1.039 \pm 0.039$. Using the same protocol, the gold standard Maximum Likelihood Estimator (MLE) showed average bias and variance-to-CRLB ratio of $(2.77 \pm 2.25) \times 10^{-5}$ cm and $1.035 \pm 0.037$ but was 50.1 times slower in our simulation. Compared to a previous non-iterative estimator (Alvarez et al), the variance-to-CLRB of TLSE is more homogenous and its average value is reduced from 9.7% to 3.9%. Average variance-to-CRLB ratio for TLSE is lower by as much as 19% in the peripheral region.

CONCLUSION
The TLSE is a computationally efficient method for implementing material decomposition technique using multi-bin PCXDs that offers noise parameters comparable to the gold standard MLE method.

CLINICAL RELEVANCE/APPLICATION
The proposed estimator is a practical method of material decomposition that can be used in clinical applications (such as angiography, virtual pre-contrast imaging) using PCXDs.
was subsequently calculated. Differences in vessel attenuation and CNR were compared between the different monoenergetic datasets. The best monoenergetic dataset was then compared to the standard 120-kV polyenergetic dataset.

RESULTS
Vessel attenuation and CNR of 70-keV CTPA datasets were superior to all other monoenergetic low-keV image datasets (all p

CONCLUSION
Virtual 70-keV monoenergetic CTPA image datasets significantly increase vessel attenuation and CNR of DE-CTPA studies, suggesting that clinical application of low-keV monoenergetic reconstructions may allow a decrease in the amount of iodinated contrast required for adequate image quality in DE-CTPA examinations.

CLINICAL RELEVANCE/APPLICATION
DE-low-keV monoenergetic imaging may allow reductions in iodinated contrast material without compromising image quality; this may be particularly relevant in patients with impaired renal function.

SSG14-07 • Half and Quarter Dose Dual Energy CT Enabled by Prior Image Constrained Compressed Sensing

John W Garrett MS (Presenter) ; Stephen T Brunner BS ; Jie Tang PhD ; Guang-Hong Chen PhD *

PURPOSE
The dose in dual-energy CT (DE-CT) studies is often high due to the decomposition of the CT images, as well as the need to acquire a high and a low energy data set. The Prior Image Constrained Compressed Sensing (PICCS) algorithm may enable half or even quarter dose acquisitions in DE-CT while retaining spatial resolution and diagnostic information.

METHOD AND MATERIALS
The PICCS reconstruction technique was adapted for use in DE-CT. It was then applied to a porcine DE-CT study (0.625 x 0.625 x 5 mm³) acquired using a GE Discovery CT750 HD scanner (GE Healthcare, Waukesha, WI) at full, half, and quarter dose using a 50/50 dose partition. Bone/water decomposition images as well as virtual monochromatic images (40-102 keV) were reconstructed using the conventional filtered backprojection (FBP) and PICCS techniques. For each technique, the background noise in the bone/water decomposition images and the contrast-to-noise ratio (CNR) for the gall bladder in the 50 keV virtual monochromatic images were measured. In addition, the images were subjectively reviewed by a diagnostic radiologist.

RESULTS
At half dose, the background noise in the PICCS bone/water images was lower than that of the full dose FBP by 24%, while the half dose FBP background noise was 44% higher. At a quarter dose, the background noise of the PICCS bone/water images was found to be within 1% of the full dose FBP images, while the quarter dose FBP was higher by 92%. In the 50 keV virtual monochromatic images, the CNR of the PICCS images was higher than that of the full dose FBP by 22% and 9% at half and quarter doses respectively. For the reduced dose FBP images the CNR was lower by 34% and 40% at the same dose levels. Radiologist review determined that the half dose PICCS bone/water and virtual monochromatic images were diagnostically equivalent to the full dose FBP images, and the quarter dose PICCS was comparable the half dose FBP.

CONCLUSION
DE-CT images reconstructed at half or quarter radiation dose with the PICCS algorithm are similar to the full dose FBP reconstruction in terms of noise and diagnostic information. As a result, the application of the PICCS framework in DE-CT enables half or quarter dose studies to be performed with no significant loss of diagnostic information.

CLINICAL RELEVANCE/APPLICATION
This study is clinically relevant because it offers the possibility of performing dual-energy CT studies at half or quarter dose in a clinical setting.
PURPOSE
Photon-counting detectors (PCD) have the ability to discriminate photons based on their energies, thus providing information on the composition of the scanned object. This work presents an algorithm called Spectral-driven Iterative Reconstruction (SPIR) that utilizes spectral information to reduce metal artifact in Computed Tomography (CT).

METHOD AND MATERIALS
A Monte-Carlo simulator was used to simulate CT acquisitions of a jaw phantom. The phantom consists of teeth, jawbone and bone marrow. One tooth was substituted with a gold implant (density 19g/cm³). The CT simulation is setup as follows: Cone-beam geometry, photon-counting detector with 6 energy bins and an X-ray source of 125 keV. In the first step of the algorithm, the simulated projection data were decomposed to determine the spatial location and density of the gold. The information of the gold implant was then incorporated into a penalized maximum likelihood reconstruction algorithm as a prior. The result from the algorithm was objectively and subjectively assessed.

RESULTS
The algorithm was able to distinguish the gold implant from other components of the phantom. The incorporation of prior information into the reconstruction algorithm delivers a notably improved image: streaking artifacts were reduced significantly without compromising the anatomical information, while the dark shadings around the dental implant were eliminated. The signal-noise-ratio (SNR) was significantly improved (13.6), when compared to FBP (2.2) or conventional iterative reconstruction (5.8). Especially the regions surrounding the implant show extreme improved diagnostic quality when using our approach (see Figure).

CONCLUSION
The incorporation of spectral information into statistical reconstruction significantly improves the diagnostic quality, while providing more information on the composition of the scanned object. Thus the implementation of PCDs does not only offer significant dose reduction but also the improvement of diagnostic image quality.

CLINICAL RELEVANCE/APPLICATION
The imminent clinical introduction of PCDs is a promising extension. It will lead to new clinical relevant applications, while also minimizes radiation exposure to the general population.
was validated using the 120kV phantom results and 120 kV scan of the same subject. In the phantom study, CT numbers were measured in ROIs of 8 different materials with nominal CT numbers ranging from -1000 to 1000 HU. In human subject studies, CT numbers were measured from 21 ROIs in fat and soft tissue.

RESULTS
For the phantom study, the relative errors of the synthesized and 120 kV CT images are 5%, 4%, 2%, 1%, 1%, 2%, 1%, 0%, for Polystyrene, LDPE, PMP, air, Teflon, Delrin, Acrylic and the background material respectively. In the Bland-Altman analysis of human subject results, the bias of CT numbers between the synthesized effective 120 kV and acquired 120 kV CT images is 0.5 HU and the limits are within 1.7 HU.

CONCLUSION
Effective 120kV CT images can be generated from a GSI dual energy CT scan with high accuracy.

CLINICAL RELEVANCE/APPLICATION
The synthesized 120 kV CT images can help clinicians make routine diagnosis together with quantitative imaging enabled by GSI imaging.