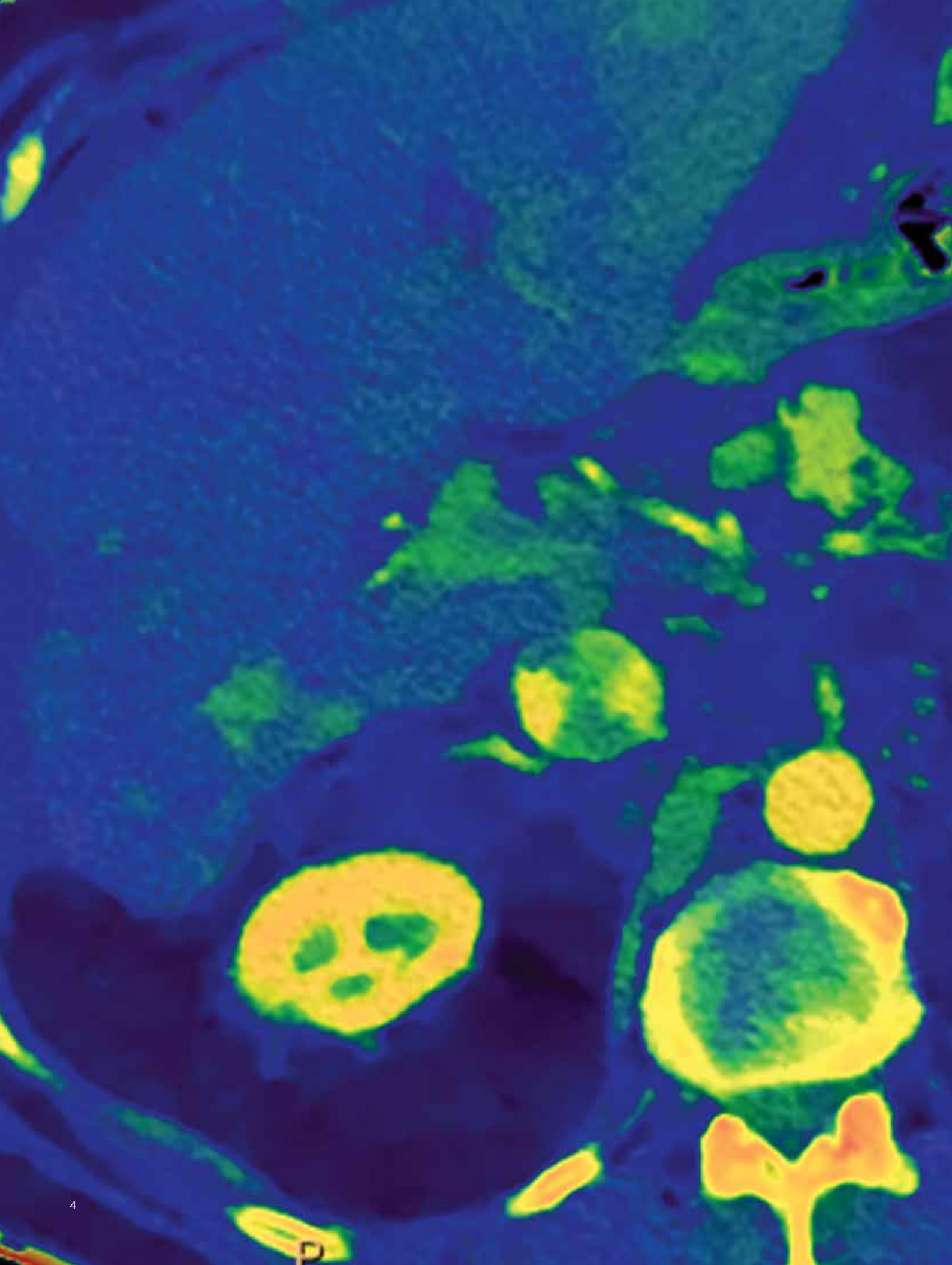
PHILIPS

Computed Tomography

Spectral detector CT

Research compendium

Contents



Introduction

As the world's first and only detector-based spectral CT, Philips Spectral detector CT delivers multiple layers of retrospective data in a single, low-dose scan. Spectral detector computed tomography (SDCT) is a breakthrough technology that uses two layers of detectors to simultaneously collect low- and high-energy data. The spectral data is used to generate conventional polyenergetic images as well as dedicated spectral images, including virtual monoenergetic (monoE) and material composition (iodine only, virtual non-contrast, Z effective) images.

Philips Spectral detector CT enables important benefits to diagnostic confidence, patient experience and workflow efficiency.

Diagnostic certainty

- More accurate diagnosis through improved tissue characterization and visualization to enhance clinical and economic outcomes
- Potential to decrease time to diagnosis by 34%*
- Enables up to 20% decrease in repeat scans**

Every scan is a spectral scan

- Spectral results 100% of the time eliminates patient selection dilemma
- No upfront clinical decision-making
- Acquire true conventional and spectral data simultaneously, in a single scan
- Scan diverse patient populations with full spectral field of view

Powerful advancements that fit your workflow

- Acquire, review, and analyze spectral results as part of a routine scan retrospectively anytime, anywhere
- Simplifies workflow across the enterprise with no compromise in image quality and dose management
- Full integration of IntelliSpace Portal, PACS, and Spectral Diagnostic Suite allows for the review and analysis of spectral data
- Simple interface allows on-demand viewing of spectral results with Spectral Magic Glass on PACS app

* Results from case studies are not predictive of results in other cases. Results in other cases may vary.

** TechValidate survey of Spectral detector CT customers. https://www.techvalidate.com/tvid/15c-0c2-709.

Spectral results derived from SDCT include iodine-based results, virtual non-contrast (VNC), virtual monoenergetic images (from 40-200 keV), effective atomic number, and uric acid to assist in clinical decision-making.

The range of spectral reconstructions can add enhanced clinical value to routine clinical diagnoses. Spectral detector CT allows for retrospective reconstruction of spectral results and improved diagnostic capabilities, even in patients who would not have been preselected for a spectral scan. Following is a summary of the clinical value of various spectral results across a range of clinical areas.

Vascular imaging[1-5]
For all vascular imaging, monoE reconstructions at low keVs increase attenuation measurements and signal-to-noise ratio (SNR). The increased attenuation at low keVs allows for improvement in image quality when the contrast enhancement is suboptimal, salvaging angiographic studies and reducing the need for additional contrast or radiation dose. Also, low monoE reconstructions allow the user to create angiography studies from a routine contrast-enhanced exam, adding additional diagnostic information to the exam. Low monoE images are used for the enhanced visualization of pathological structures in pulmonary angiography exams. Carotid in-stent stenosis in high-attenuation metallic stents can be more confidently evaluated using Z Effective spectral results produced by Spectral detector CT.

Thoracic imaging[6]
Spectral results offer a range of clinical benefits in thoracic imaging. The low keV monoE images allow for improved image quality on contrast-enhanced chest and angiographic studies, reducing suboptimal exams. High monoE spectral results reduce metal artifacts from CT images and improve image quality. Iodine density and Z Effective images provide enhanced visualization of perfusion in lung parenchyma and aid the clinician in assessment of the hemodynamic significance of pulmonary embolism or a perfusion defect caused by a tumor. MonoE images allow for improved assessment of lung tumors and lymph nodes in the mediastinal areas. MonoE and iodine-based spectral results also allow for improved and early assessment of response to therapy, influencing the treatment protocol and overall patient care.

Musculoskeletal (MSK) imaging[7]
It is very important in musculoskeletal imaging to visualize the bones, tendons, joints, and surrounding areas. Spectral results allow identification of monosodium urate crystals in joints, aiding in the visualization of gout. High monoE images help to reduce metal artifacts, aiding visualization of tendons and tissues around metal implants.

Genitourinary imaging[8,9]
Genitourinary applications of spectral CT allow for stone characterization in kidneys. Spectral results aid in material characterization and differentiation of uric acid, calcium, and non-uric acid stones. MonoE, Z Effective, and iodine-based spectral results can assist the user in tumor (renal or adrenal mass) detection and characterization. Virtual non-contrast spectral results allow for reduction of a non-contrast phase in a multi-phase renal exam. Optimal visualization and improvement in image quality of the kidney parenchyma can be achieved on Spectral detector CT images with monoE image reconstruction at 60-70 keV.

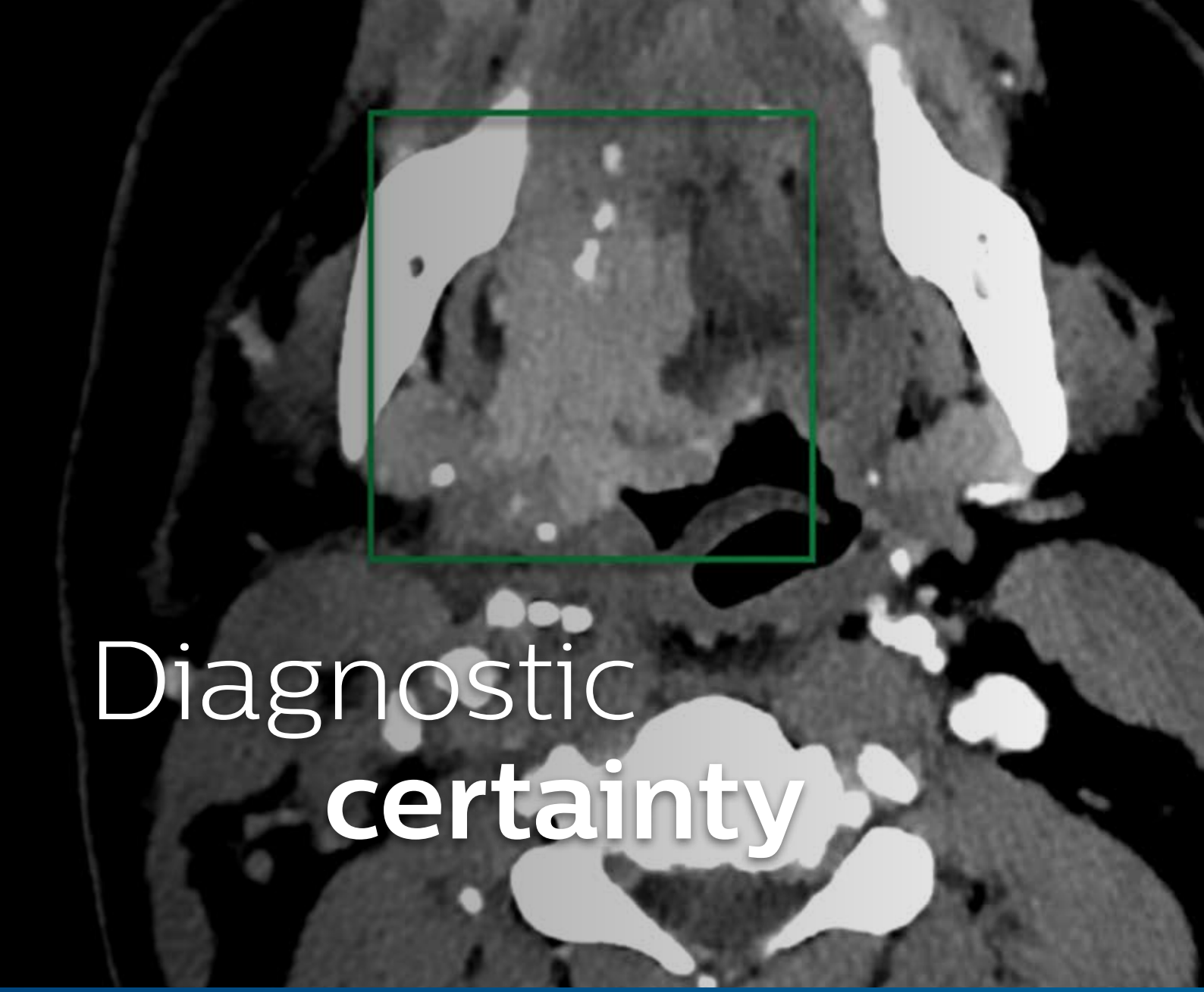
Cardiac imaging[10-14]
Cardiac applications of spectral CT include beam hardening reduction at high monoE reconstructions and salvaging suboptimal angiography studies using low monoE images. High monoE images can be used for reduction in calcium blooming.

Virtual non-contrast images can be used to eliminate a non-contrast phase in coronary exams. They can also aid the clinician in virtual calcium score calculation.

Neuro imaging[15]
Neuroradiological applications of spectral CT include virtual non-contrast imaging and improved differentiation of gray and white matter using low monoE images. Iodine-based images and Z Effective images allow for improved lesion detection and characterization. Iodine maps and Z Effective also aid in the visualization of perfusion deficit in the brain tissue.

This compendium summarizes more than 20 clinical studies, white papers, and other publications that show a growing body of evidence that the spectral detector technology available on Philips Spectral detector CT offers clear diagnostic benefits. Compared with conventional CT, SDCT produces scans with less image noise and lower incidence of beam hardening from artifacts, while requiring a low dose of radiation and fewer repeat scans.

A global spectral research network
Researchers around the world are making significant contributions to the body of knowledge surrounding SDCT. Studies are being conducted in the areas of oncology, orthopedics, cardiology and pulmonology, among others.



Diagnostic **certainty**

The following studies highlight how spectral detector technology on the Spectral detector CT enables more confident diagnosis through improved tissue characterization and visualization to enhance clinical and economic outcomes.

All these studies show improvements in diagnostic confidence through the use of spectral results obtained from the Spectral detector CT.

Improved liver lesion conspicuity using dual-layer spectral detector CT

APA Yoon, Jeong Hee MD, et al. Double Low-Dose Dual-Energy Liver CT in Patients[3] at High-Risk of HCC, Investigative Radiology (June 2020) Volume 55, Issue 6, p 340-348, doi: 10.1097/RLI.0000000000000643
https://journals.lww.com/investigativeradiology/Abstract/2020/06000/

Purpose

This Seoul National University Hospital (SNUH) study looked at clinical feasibility of using dual-layer CT to simultaneously reduce radiation and contrast media dose for patients at risk for hepatocellular carcinoma.

Method

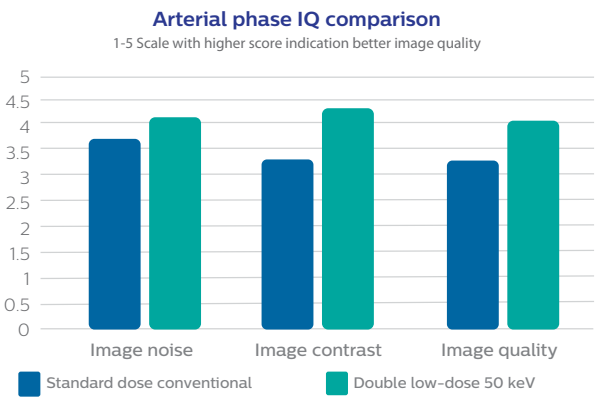
- The study included 67 patients randomized between group A (standard-dose group) and Group B (double low-dose group). Both radiation dose and contrast dose were reduced in Group B as compared to Group A. All the scans were acquired on a spectral detector CT. iDose[4] conventional reconstructions and monoE images at 50 keV were reconstructed for the patients.
- Four fellowship-trained radiologists with 3-7 years of experiences independently reviewed the images. Image noise, image contrast and overall image quality were scored on a five-point scale. Lesion conspicuity and size of the focal liver lesions were recorded and statistical analysis was used to compare the different results from the study.

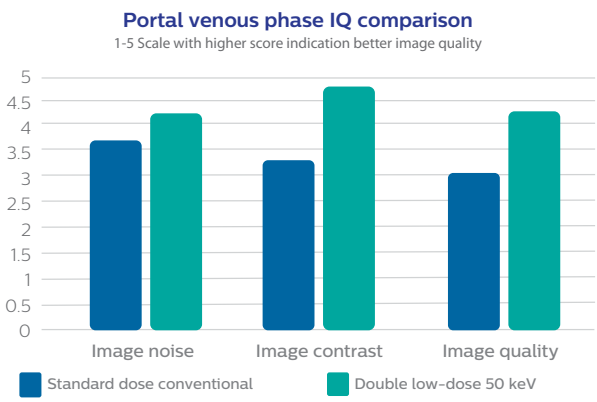
Results

- Compared with the standard-dose group, total DLP for the scans in the double low-dose group (Group B) was reduced by 30%. The amount of contrast media administered was also significantly lower in the double low-dose group than in the standard-dose group (116.9 ± 15.7 ml vs 83.1 ± 9.9 ml).
- No participants had to be rescanned due to suboptimal image quality resulting from the reduced radiation and contrast dose.
- A total of 171 focal liver lesions were identified which included hepatocellular carcinoma, dysplastic nodules, hemangiomas, regenerative nodules, metastasis, treated lesion other than lipiodol, adenocarcinoma and focal fat deposition.
- Lesion conspicuity and lesion sensitivity was significantly higher on 50 keV images of the double low-dose group than images of the standard-dose group.
- Double low-dose 50 keV images showed significantly less noise, stronger image contrast and better image quality than standard-dose iDose[4] images. On quantitative analysis, contrast-to-noise ratios of the aorta and portal vein were significantly higher on double low-dose 50 keV images than on standard-dose conventional images.
- All readers assessed that image noise, image contrast and overall image quality were better on 50 keV images than on conventional images.

Conclusion

Low monoE spectral CT images (50 keV) were able to provide better overall image quality with improved focal liver lesion conspicuity, while reducing radiation and contrast media doses.





Low volume iodine contrast CT for TAVR using spectral detector CT assessment

Cavallo AU, et al. Low dose contrast CT for transcatheter aortic valve replacement assessment: Results from the prospective SPECTACULAR study (spectral CT assessment prior to TAVR), Journal of Cardiovascular Computed Tomography. 2019;14(1):68–74. https://www.journalofcardiovasculartct.com/article/S1934-5925(19)30182-0/fulltext

Purpose

With many patients undergoing transcatheter aortic valve replacement (TAVR) being fragile with impaired renal function, high volume of iodine contrast material (ranging from 90-140 ml) necessary for TAVR CTA poses a significant challenge. This study, using only 25 ml of iodinated contrast, sought to evaluate and compare 40 keV VMI (virtual monoE images) to 120 kV conventional images.

Method

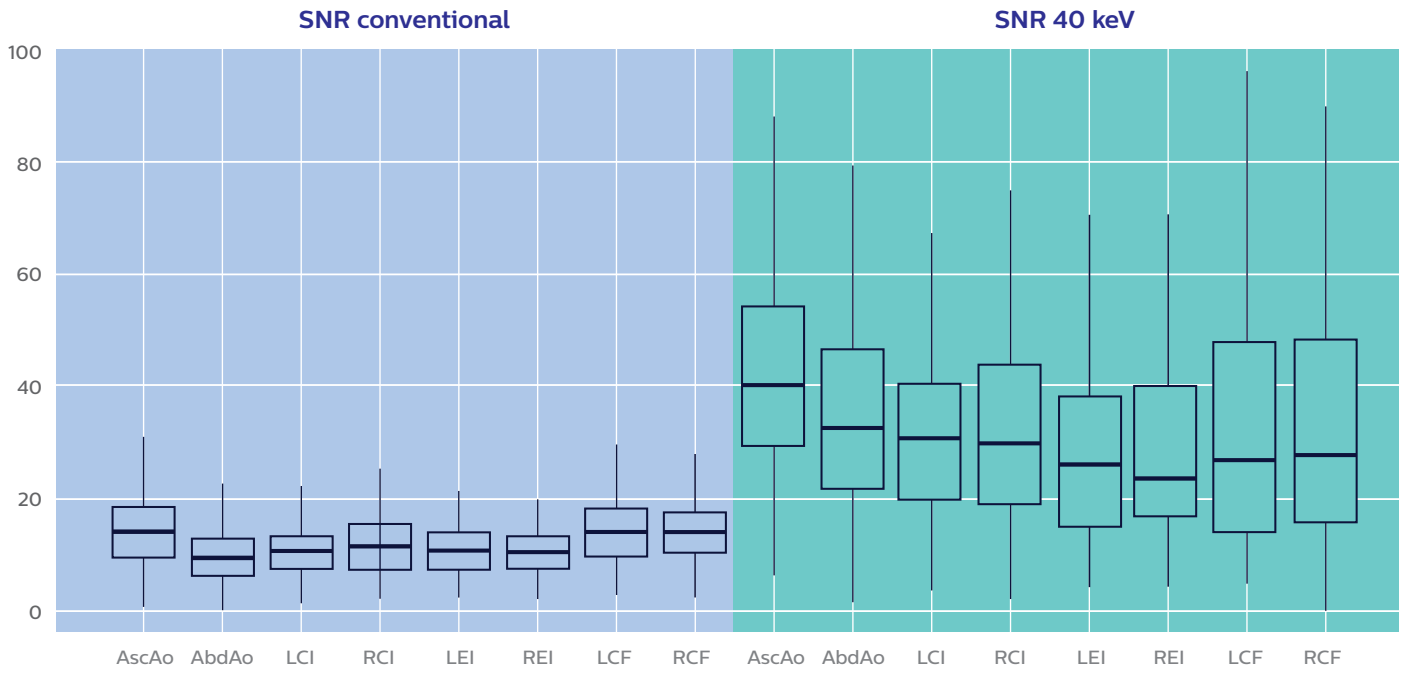
- In this prospective study, Philips Spectral detector CT was used to analyze 116 patients undergoing evaluation for TAVR implantation. Retrospectively gated chest CTA was followed by an abdominal CT. 25 ml of iodinated contrast medium was injected at 3cc/sec injection rate with saline chaser.
- Resulting data was reconstructed at 40 keV monoE spectral result as well as 120 kV conventional images for performance evaluation and comparisons.
- Two experienced cardiovascular imagers performed image analysis for TAVR planning which included measurement of aortic root and vascular access planning.

Results

Study found that, compared to conventional 120 kv images, 40 keV VMI had significantly better SNR and CNR values and offered advantage of delineating catheter access vessels at significantly reduced contrast volume. Aortic root measurements had good concordance between VMI and conventional images which demonstrated viability of using 40 keV images for TAVR planning.

Conclusion

Spectral detector CT with significantly low iodine contrast volume is a reliable technique for TAVR planning. Compared to conventional 120 kV images, 40 keV VMI images provide improved SNR and CNR with excellent image quality, allowing for accurate measurement and comprehensive assessment of aortic root and access vessels.


SNR conventional
SNR 40 keV
100
80
60
40
20
0
AscAo
AbdAo
LCI
RCI
LEI
REI
LCF
RCF
AscAo
AbdAo
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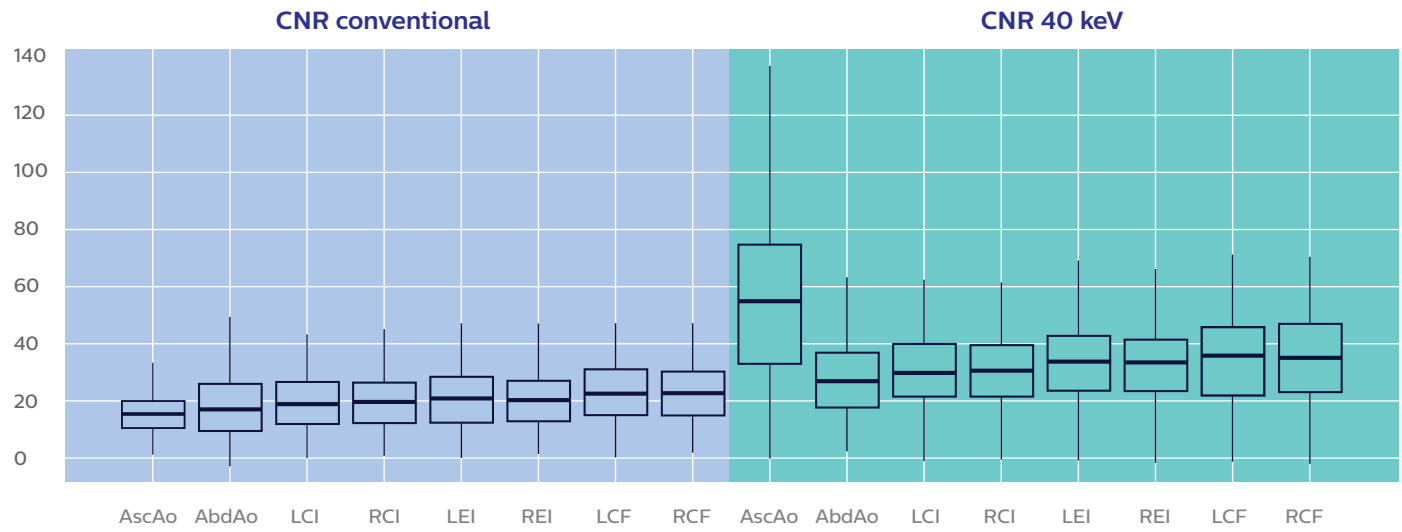
RCI
LEI
REI
LCF
RCF


CNR conventional
CNR 40 keV
140
120
100
80
60
40
20
0
AscAo
AbdAo
LCI
RCI
LEI
REI
LCF
RCF
AscAo
AbdAo
LCI
RCI
LEI
REI
LCF
RCF

Low dose and low contrast medium CCTA using Spectral detector CT

Yan Y, et al., Low Dose and Low Contrast Medium Coronary CT Angiography Using Dual-Layer Spectral Detector CT. International Heart Journal. 2019;60(3):608–617.
https://doi.org/10.1536/ihj.18-340

Purpose

This study investigated the performance of low keV monoE reconstructions from spectral detector CT (SDCT) of spectral coronary computed tomography angiography (CCTA) using reduced radiation dose and contrast media.

Method

- All studies were performed on Spectral detector CT. Scans were performed on symptomatic patients suspected for coronary artery disease, referred for CCTA exams between April 2017 and June 2017. Total of 60 patients were enrolled for the study and randomly assigned to two separate groups – 120 kVp (spectral group A) and 100 kVp (conventional group B). For both study groups, Dose Right Index (automatically adjusts mAs settings for patient size to ensure consistent noise and image quality) of 15 was used to ensure lower radiation dose.
- All CCTA exams were performed with prospective axial scan mode using bolus tracking scan trigger with 36 ml of contrast media injected at 3 cc/sec.
- Images from Group A were reconstructed using spectral reconstruction algorithm while images from Group B were reconstructed using iDose[4] (noise reduction algorithm). All reconstructions were sent to IntelliSpace Portal Spectral Workstation for interpretation.
- Two experienced cardio-radiologists performed qualitative image quality assessments using Likert scale with modified 18-segment classification system.

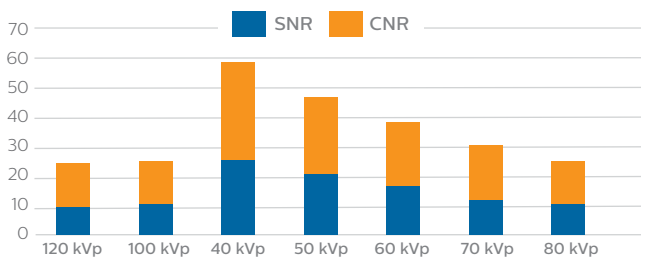
Results

- Compared to 100 kVp conventional images, 40–60 keV monoE images showed significantly higher attenuation in the aortic root, LAD, LCX and RCA, correlated with increased CNR and SNR at 40–60 keV images. Image noise remained minimal even at lower 40–50 keVs.
- While maintaining similar radiation dose level as conventional 100 kVp scan protocols (approximately 1.5 mSv), image quality resulting from the spectral detector CT was either equivalent or superior to that of 100 kVp conventional images.
- Low keV monoE reconstructions' ability to boost iodine contrast facilitated reduction of IV contrast volume by 40–60% (36 mL compared to 60-100 ml used in traditional scans) in CCTA exams.

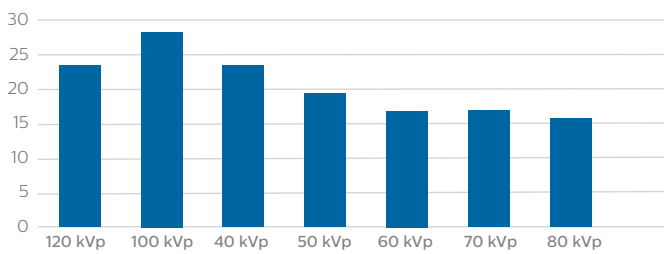
Conclusion

Compared to conventional 100 kVp low dose optimized scan protocols, low keV monoE reconstructions from a spectral detector CT provides significantly improved image quality and improved SNR and CNR, while allowing for reduced radiation dose and contrast media.

Coronary vessels average CNR and SNR



Coronary vessels average noise



Improvement of image quality in unenhanced dual-layer CT of the head using virtual monoenergetic images compared with polyenergetic single-energy CT

Neuhaus V, et al. Investigative Radiology. Aug 2017;52(8):470–476.
https://www.ncbi.nlm.nih.gov/pubmed/28422806

Neurological imaging

Purpose

- To compare virtual monoE images and polyenergetic images reconstructed from unenhanced dual-layer detector computed tomography (DLCT) of the head.
- To determine kiloelectron volt (keV) levels that optimize image quality, particularly the gray-white matter contrast, and reduce beam hardening artifacts caused by the skull.

Method

- Institutional review board approval was obtained.
- 40 patients who received DLCT were included in this retrospective study. Of these patients, 22 were women and 18 were men. The average age was 61.5 ± 14.3 years.
- Virtual monoE images were reconstructed from spectral base images at 40 keV to 120 keV.
- To calculate signal-to-noise ratio and contrast-to-noise ratio, attenuation and standard deviation of supratentorial gray and white matter were measured in virtual monoE and polyenergetic images.
- Beam hardening artifacts were detected close to the calvarium and in the posterior fossa.
- Radiologists rated the assessment of gray-white matter differentiation and of the subcalvarial space, as well as the artifacts caused by the skull and image noise. Student t-test and Wilcoxon test were used to determine significance.

Results

- Compared with polyenergetic images, superior signal-to-noise ratio and superior contrast-to-noise ratio of gray and white matter were observed in virtual monoE images at low keV ($P < 0.0001$).
- Subcalvarial artifacts were significantly lower at 120 keV ($P < 0.02$).
- Artifacts measured in the posterior fossa were generally lower at high keV levels; however, no statistical significance was detected.
- Virtual monoE images were rated superior to polyenergetic images in regard to all four criteria ($P < 0.0001$). The observers reported an optimal radiological assessment of gray-white matter differentiation at 65 keV and optimal assessment of subcalvarial space at 120 keV.

Conclusion

In comparison to polyenergetic images, virtual monoE images reconstructed from unenhanced DLCT of the head at 65 keV and 120 keV allow to optimize gray-white matter contrast and reduce beam hardening artifacts caused by the skull, respectively.

Comparison of subjective image quality criteria rated in polyenergetic and virtual monoenergetic images

Criteria	Polyenergetic images	Monoenergetic images	Significance
GWMA	2.88 ± 0.35*	4.77 ± 0.29*	P < 0.0001
SSA	3.1 ± 0.36*	4.95 ± 0.18*	P < 0.0001
Artifacts	3.33 ± 0.28*	4.77 ± 0.27*	P < 0.0001
Noise	2.55 ± 0.34*	4.5 ± 0.19*	P < 0.0001

*Data are presented as mean ± SD.
GWMA indicates assessment of gray-white matter differentiation; SSA, assessment of subcalvarial space.

Monoenergetic reconstructions for imaging of coronary artery stents using spectral detector CT: in-vitro comparison to conventional image

Hickethier T, et al. Journal of Cardiovascular Computed Tomography. 2017;11(1):33–39.
https://www.ncbi.nlm.nih.gov/pubmed/28096049

Cardiac imaging

Purpose

To systematically investigate the influence of different monoE reconstructions on the visualization of coronary stent lumen in comparison to conventional images.

Method

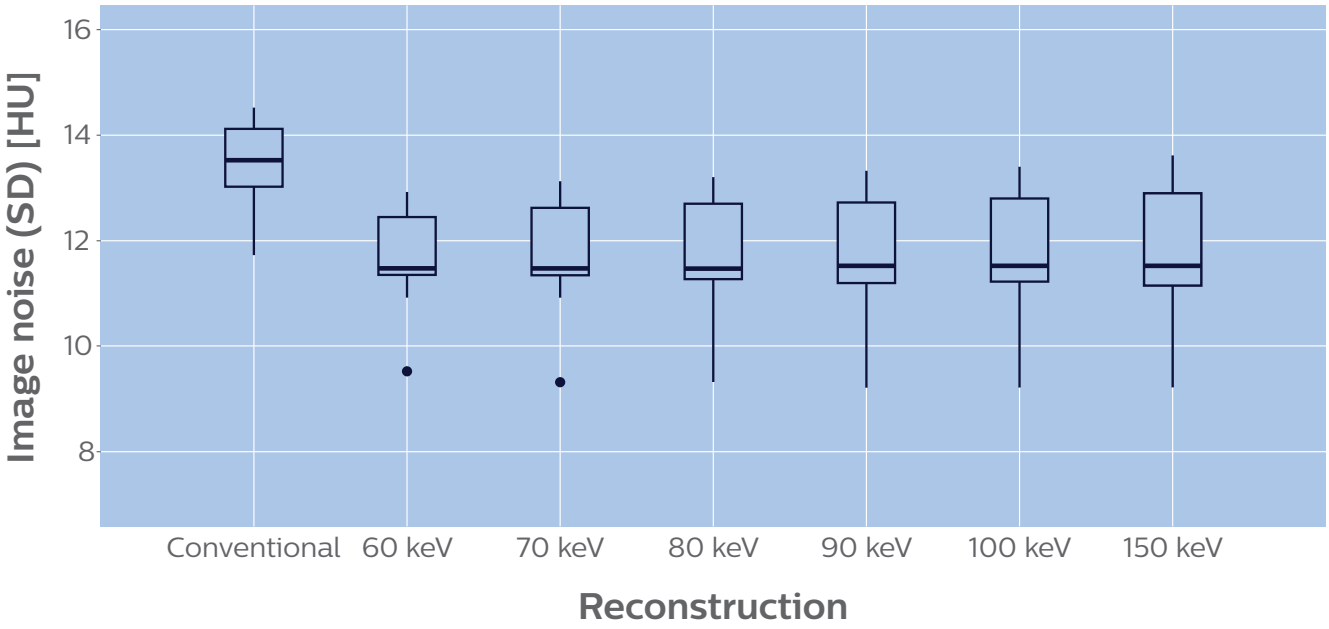
- 10 different coronary stents (diameter 3.0 mm) embedded in plastic tubes filled with contrast agent (500 HU) were scanned on a spectral detector CT (120 keV, 125 mAs).
- Images were reconstructed (0.67 mm slice thickness, 0.35 mm increment) with a stent-specific conventional reconstruction kernel and six different monoE settings (60, 70, 80, 90, 100, 150 keV).
- Image quality for each stent and reconstruction was quantified using established parameters:
  - Image noise (standard deviation within a standardized region of interest).
  - In-stent attenuation difference (mean attenuation difference between stented and non-stented lumen).
  - Visible lumen diameter (mean visible diameter of the stented tube).

Results

- Image noise was significantly lower in all monoE data sets compared to conventional images.
- The visible lumen diameter was significantly greater in monoE data with higher keV levels than in conventional images.

Conclusion

In comparison to conventional CT images, well-established parameters for objective assessment of CT image quality for coronary stents are significantly improved by utilization of monoE reconstructions with adequate keV levels derived from data acquired using SDCT.



Graphical depiction of the image noise results (lower is superior) for conventional as well as for the different monoenergetic reconstructions.

Quantifying potential reduction in contrast dose with monoenergetic images synthesized from dual-layer spectral detector CT

Tsang D, Merchant T, Merchant S, Smith H, Yagil Y and Hua C. The British Journal of Radiology. 2017;90(1078):20170290.
https://doi.org/10.1259/bjr.20170290

Vascular imaging

Purpose

To estimate the potential dose reduction in iodinated contrast when interpreting monoenergetic (monoE) images from spectral detector CT.

Method

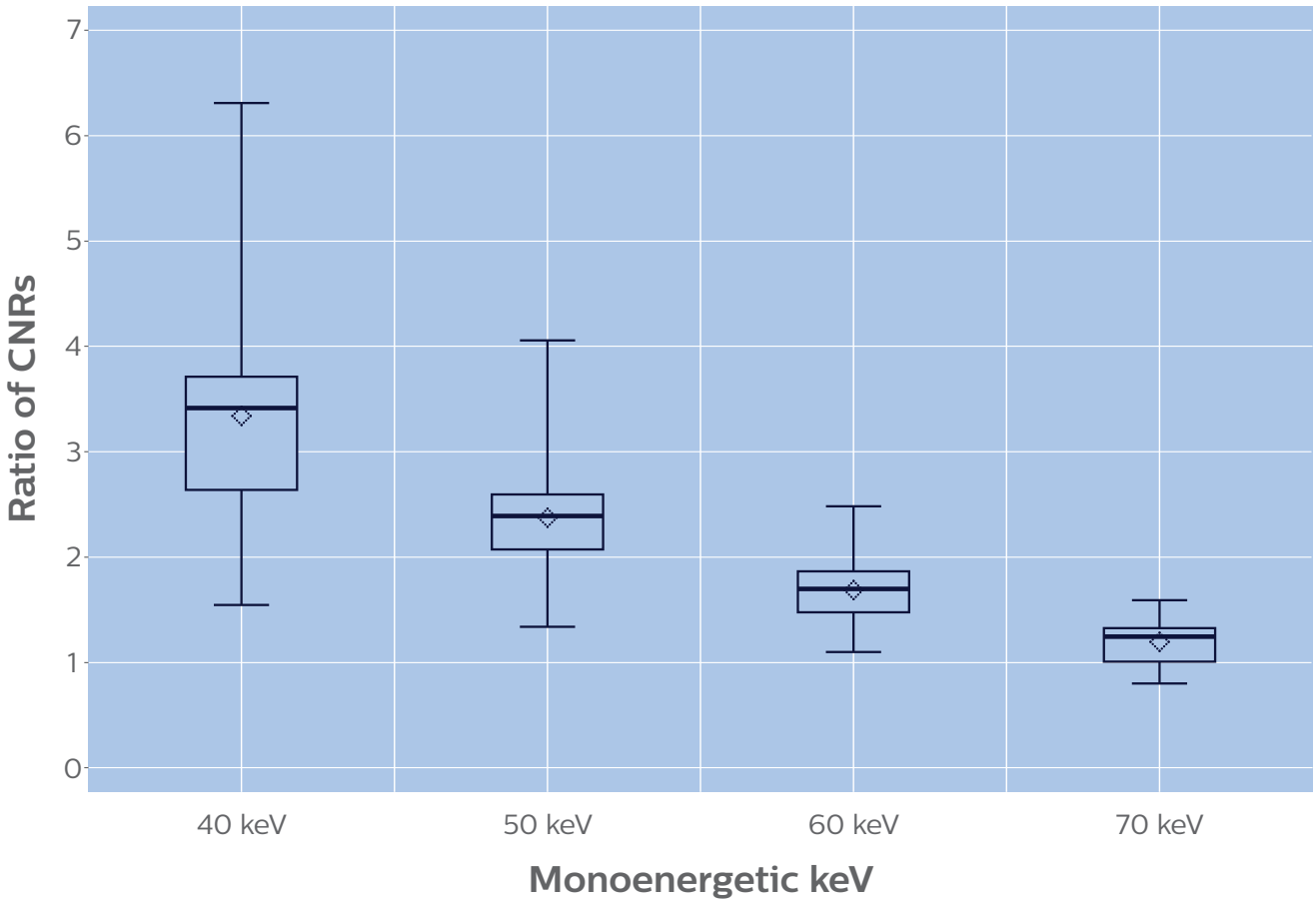
- 51 pediatric patients received contrast-enhanced CT simulation for radiation therapy using the single-source, dual-layer, detector-based spectral detector CT.
- The contrast-to-noise ratios (CNRs) of blood vessels were measured relative to surrounding soft tissue.
- CNRs on monoE 40–70 keV images were compared with polychromatic 120 kVp images.
- To compare with in vivo results, a phantom with iodine inserts (2–20 mg ml–1 concentration) was scanned and CNRs were calculated relative to water background.

Results

- MonoE keV and body site had significant effects on CNR ratio ($p < 0.0001$).
- Across all body sites, the mean CNR ratio (monoE/polychromatic CNR) was 3.3 (20th percentile [%20] 2.6), 2.4 (%20 2.1), 1.7 (%20 1.5), 1.2 (%20 1.0) for 40, 50, 60 and 70 keV images, respectively.
- Image noise was highest at 40 keV and lowest at 70 keV.
- Phantom measurements indicated that the same CNR as 120 kVp images can be achieved with a 4.0-fold lower iodine concentration on 40 keV images and 2.5-fold lower on 50 keV images.

Conclusion

- 50 keV monoE images provided the best balance of improved CNR on all studies (mean 2.4-fold increase in vivo) for enhancing vessels vs image noise.
- A 50% reduction in contrast dose on a 50 keV image should maintain comparable or better CNR as compared with polychromatic CT in over 80% of CT studies.



Plot of CNR ratio vs. monoenergetic keV. Higher CNR ratio represents greater apparent enhancement of blood vessels as compared with polychromatic 120 kVp images. Horizontal lines represent median, first and third quartiles, while whiskers represent range and diamonds represent mean.

The effects of iodine attenuation on pulmonary nodule volumetry using novel dual-layer computed tomography reconstructions

den Harder AM, Bangert F, van Hamersvelt RW, et al. Eur Radiol. 2017;27:5244–5251.
https://doi.org/10.1007/s00330-017-4938-1

Thoracic imaging

Purpose

To assess the effect of iodine attenuation on pulmonary nodule volumetry using virtual non-contrast (VNC) and monoE reconstructions.

Method

- A consecutive series of patients who underwent a contrast-enhanced chest CT scan were included.
- Images were acquired on the novel dual-layer Philips Spectral detector CT.
- Conventional reconstructions as well as VNC and monoE images at different keV levels were used for nodule volumetry.

Results

- 24 patients with a total of 63 nodules were included.
- Conventional reconstructions showed a median (interquartile range) volume and diameter of 174 (87 - 253) mm, 3 and 6.9 (5.4 - 9.9) mm, respectively.
- VNC reconstructions resulted in a significant volume reduction of 5.5% (2.6 - 11.2%; $p<0.001$).
- MonoE reconstructions showed a correlation between nodule attenuation and nodule volume (Spearman correlation 0.77, [0.49 - 0.94]).
- Lowering the keV resulted in increased volumes, while higher keV levels resulted in decreased pulmonary nodule volumes compared to conventional CT.

Conclusion

- Novel dual-layer spectral CT offers the possibility to reconstruct VNC and monoE images.
- Those reconstructions show that higher pulmonary nodule attenuation results in larger nodule volumes.
- This may explain the reported underestimation in nodule volume on non-contrast enhanced compared to contrast-enhanced acquisitions.

	Absolute difference (mm^3)	Relative difference (%)	*p* value
All Nodules			
Conventional vs VNC*	-9.6 [-24.6 – -3.4]	-5.5 [-11.2 – -2.6]	*p*< 0.001
Conventional vs 40 keV**	20.1 [8.5 – 43.8]	11.2 [6.9 – 20.9]	*p*< 0.001
Conventional vs 70 keV	0.1 [-4.4 – 9.5]	0.1 [-4.2 – 2.9]	*p*= 0.540
Conventional vs 100 keV	-6.7 [-14.7 – -1.5]	-3.7 [-7.3 – -1.2]	*p*< 0.001
Conventional vs 130 keV	-6.7 [-17.9 – -2.4]	-4.8 [-8.9 – -1.6]	*p*< 0.001
Conventional vs 160 keV	-9.5 [-21.2 – -4.0]	-5.6 [-9.1 – -2.7]	*p*< 0.001
Conventional vs 200 keV	-8.8 [-22.8 – -3.1]	-6.3 [-11.0 – -2.2]	*p*< 0.001
Nodules ≤ 200 mm^3			
Conventional vs VNC	-7.2 [-13.4 – -3.1]	-9.0 [-13.5 – -2.9]	*p*< 0.001
Conventional vs 40 keV	12.4 [7.8 – 25.0]	12.8 [7.6 – 21.7]	*p*< 0.001
Conventional vs 70 keV	-0.2 [-3.4 – 3.8]	-0.2 [-4.2 – 2.4]	*p*= 0.904
Conventional vs 100 keV	-4.3 [-8.5 – -1.5]	-4.8 [-7.6 – -1.6]	*p*< 0.001
Conventional vs 130 keV	-6.2 [-9.7 – -2.6]	-5.2 [-9.2 – -2.3]	*p*< 0.001
Conventional vs 160 keV	-6.8 [-11.9 – -3.3]	-6.5 [-10.5 – -3.5]	*p*< 0.001
Conventional vs 200 keV	-6.9 [-12.4 – -2.4]	-7.3 [-11.4 – -2.5]	*p*< 0.001
Nodules > 200 mm^3			
Conventional vs VNC	-26.8 [-79.7 – -6.4]	-4.0 [-8.0 – -1.3]	*p*< 0.001
Conventional vs 40 keV	52.4 [24.8 – 120.1]	10.8 [3.5 – 14.1]	*p*< 0.001
Conventional vs 70 keV	1.7 [-27.3 – 20.5]	0.7 [-3.6 – 3.0]	*p*= 0.757
Conventional vs 100 keV	-14.2 [-57.5 – 0.7]	-2.7 [-4.7 – 0.2]	*p*< 0.007
Conventional vs 130 keV	-17.9 [-62.3 – 0.4]	-3.4 [-7.6 – -0.1]	*p*< 0.004
Conventional vs 160 keV	-21.6 [-69.5 – -6.7]	-3.8 [-6.7 – -2.3]	*p*< 0.001
Conventional vs 200 keV	-41.4 [-65.2 – -4.9]	-4.0 [-9.0 – -1.3]	*p*= 0.005

Negative differences mean that the nodules were larger on conventional reconstructions. Bonferroni corrected *p*-values below 0.007 were considered significant.

* Virtual non-contrast (VNC)
** Kiloelectron Volt (keV)

Image quality evaluation of dual-layer spectral detector CT of the chest and comparison with conventional CT imaging

Doerner J, et al. European Journal of Radiology. 2017;93:52–58.
https://www.ncbi.nlm.nih.gov/pubmed/28668431

Thoracic imaging

Purpose

To evaluate image quality parameters of virtual monoenergetic (monoE) and conventional (CR) imaging derived from a dual-layer spectral detector CT (DLCT) in oncological follow-up venous phase imaging of the chest and comparison with conventional multi-detector CT (CR_{MDCT}) imaging.

Method

- A total of 55 patients who had oncologic staging with conventional CT and DLCT of the chest in venous phase were included in this study.
- Established image quality parameters were derived from all data sets in defined thoracic landmarks.
- Attenuation, image noise, and signal- and contrast-to-noise ratios (SNR, CNR) were compared between CR_{DLCT} and monoE as well as CR_{MDCT} imaging.
- Two readers performed subjective image analysis.

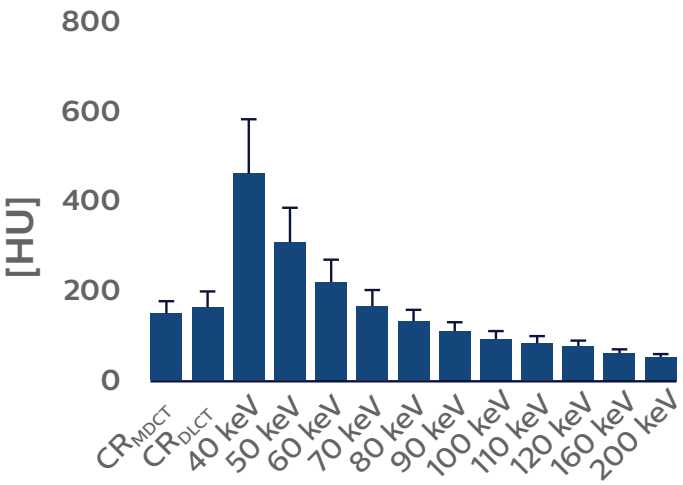
Results

- CR_{MDCT} showed significant lower attenuation values compared to CR_{DLCT} and monoE at 40-70 keV ($p \leq 0.05$).
- MonoE at 40-70keV revealed significantly higher attenuation values compared to CR_{DLCT} ($p < 0.001$).
- Noise was statistically lower in CR_{MDCT} compared with CR_{DLCT} and monoE at 40 keV.
- All monoE levels showed significantly lower noise levels compared to CR_{DLCT} ($p < 0.001$).
- SNR was not significantly different between CR_{MDCT} and CR_{DLCT}.
- SNR values were significantly increased for monoE at 40-80 keV compared to CR_{MDCT} and CR_{DLCT} ($p < 0.001$).
- CR_{DLCT} and monoE (40-70 keV) from DLCT revealed significantly higher CNR values than CR_{MDCT} ($p < 0.001$).
- In subjective analysis, monoE at 40 keV surpassed all other image reconstructions except for noise in monoE at 70 keV.

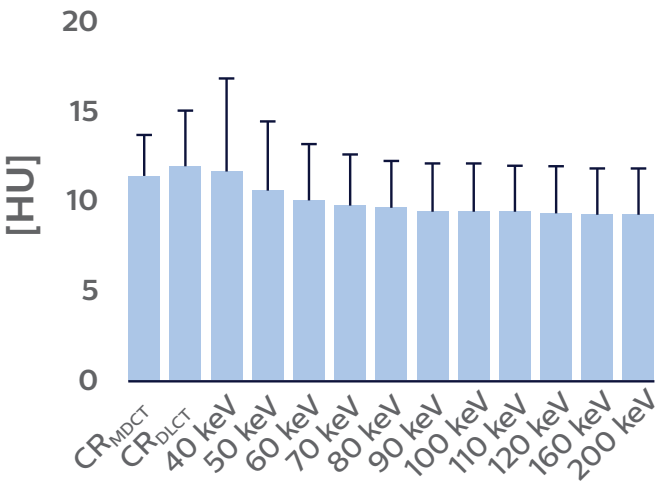
Conclusion

In dual-layer spectral detector CT, monoE at low keV showed superior image quality compared to conventional images derived from the same system and may therefore be added to clinical routine imaging protocols.

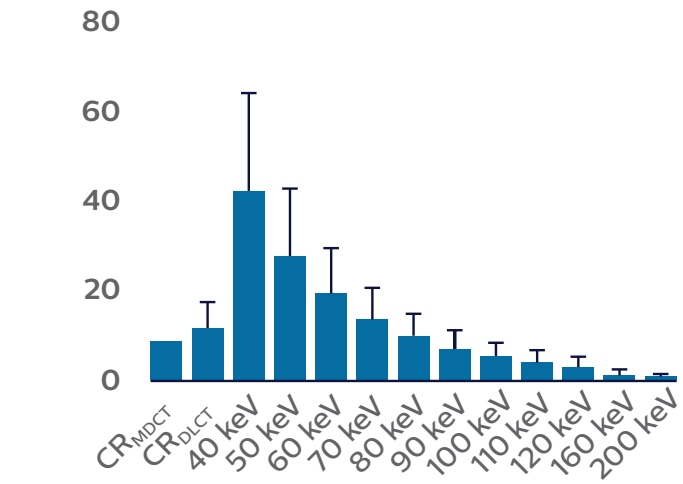
Absolute attenuation



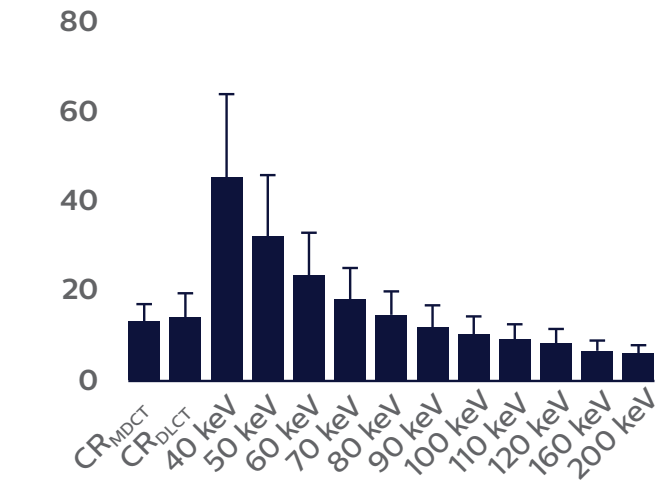
Noise



CNR



SNR



Graphs show distinct higher absolute attenuation values with low noise values and consecutive markedly increased contrast-to-noise (CNR) and signal-to-noise ratios (SNR) in monoE imaging at low energy. CR_{MDCT} conventional reconstruction from multi-detector CT; CR_{DLCT} conventional reconstruction from dual-layer spectral detector CT.

Intra-individual comparison between abdominal virtual monoenergetic spectral and conventional images using a novel spectral detector CT

Doerner J, Wybranski C, Byrtus J, Houbois C, Hauger M, Heneweer C, et al. PLOS ONE. 2017;12(8). e0183759.
https://doi.org/10.1371/journal.pone.0183759

Abdominal imaging

Purpose

To quantitatively and qualitatively assess abdominal arterial and venous phase contrast-enhanced spectral detector computed tomography (SDCT) virtual monoenergetic (monoE) data sets in comparison to conventional CT reconstructions provided by the same system.

Method

- Conventional and monoE images at 40–120 keV levels with a 10 keV increment as well as 160 and 200 keV were reconstructed in abdominal SDCT data sets of 55 patients.
- Attenuation, image noise, and contrast (and signal-to-noise ratios (CNR, SNR) of vessels and solid organs were compared between monoE and conventional reconstructions.
- Two readers assessed contrast conditions, detail visualization, overall image quality, and subjective image noise with both fixed and adjustable window settings.

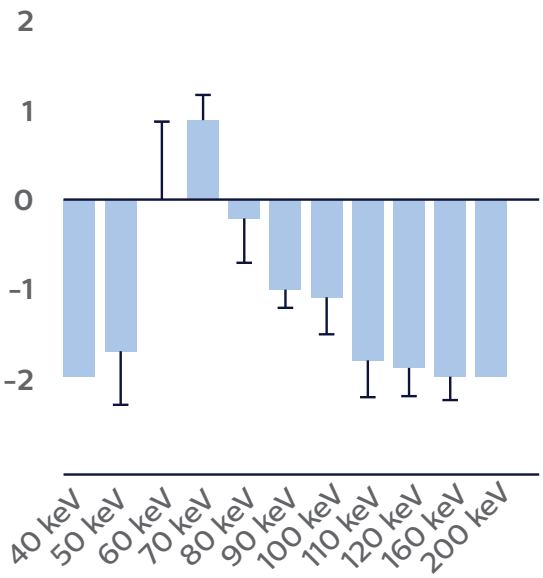
Results

- Attenuation, CNR and SNR of vessels and solid organs showed a stepwise increase from high to low keV reconstructions in both contrast phases while image noise stayed stable at low keV monoE reconstruction levels.
- Highest levels were found at 40 keV monoE reconstruction ($p < 0.001$), respectively.
- Solid abdominal organs showed a stepwise decrease from low to high energy levels in regard to attenuation, CNR and SNR with significantly higher values at 40 and 50 keV, compared to conventional images.
- The 70 keV monoE was comparable to conventional polyenergetic reconstruction ($p \geq 0.99$).
- Subjective analysis displayed best image quality for the 70 keV monoE reconstruction level in both phases at fixed standard window presets and at 40 keV if window settings could be adjusted.

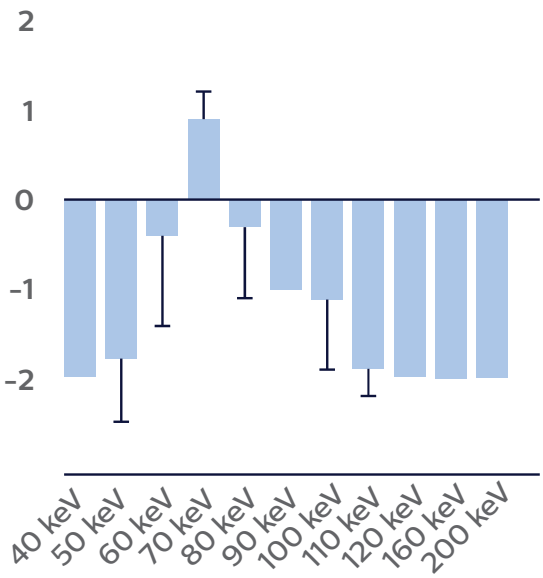
Conclusion

SDCT-derived low keV monoE showed markedly increased CNR and SNR values due to constantly low image noise values over the whole energy spectrum from 40 to 200 keV.

Overall quality arterial phase



Overall quality venous phase



Waterfall plot showing overall image rating in arterial and venous contrast phase with standard abdominal window settings where 0 corresponds to the reference standard (conventional imaging). Best image quality was rated for monoE at 70 keV in arterial phase and 80 keV in venous phase.

Differentiation of clot composition using conventional and dual-energy computed tomography

Borggrefe J, Kottlors J, Mirza M, et al. Clin Neuroradiol. 2017;28:515-522.
https://doi.org/10.1007/s00062-017-0599-3

Cardiac imaging

Purpose

To investigate thrombus composition of histologically defined ovine blood clots with unenhanced and contrast-enhanced CT using spectral detector CT (SDCT).

Method

- Ovine blood clot types containing defined amounts of red blood cells – **pure fibrin clots** (RBC 0% ± 0, fibrin 100% ± 0), **mixed clots** (RBC 35.1% ± 4.11, fibrin 79.2% ± 5.6) and **red clots** (RBC 99.05% ± 1.14, fibrin 0.95% ± 1.14) – were scanned on the spectral detector CT (a) in a tube containing saline, (b) five minutes, and (c) three days after exposure to a 1:50 dilution of iohexol.*
- The attenuation of the clots was measured in Hounsfield units (HU) in conventional CT data sets as well as virtual non-contrast reconstructions (VNC) of non-enhanced and contrast-enhanced SDCT in a blinded and randomized fashion.
- Statistical analysis was conducted with ANOVA, Spearman's correlation, linear and multivariable regression models.

Results

- In unenhanced scans, clots differed in density with linear interrelation (fibrin 23.6 ± 1.1, mixed 34.9 ± 1.6, red 46.7 ± 1.6, mean HU ± SD).
- The blood clots did not show any overlap of density in the native scans and VNC at different time points ($p < 0.0001$ for each setting and clot type). However, they could not be differentiated after initial contrast exposure (fibrin 108.5 ± 7.8, mixed 105.3 ± 3.5, red 104.8 ± 3.8, mean HU ± SD).
- After prolonged exposure, the fibrin-rich clots showed a significant increase of density due to further uptake of contrast medium (fibrin 163.6 ± 3.6, mixed 138.3 ± 4.1, red 109.6 ± 5.4, mean HU ± SD).
- In multivariable models, native CT density and contrast enhancement were independent variables associated with thrombus type ($p < 0.01$ each).

Conclusion

The fibrin content in blood clots is strongly associated with contrast uptake. As previously shown, the density of the clot formations in native CT scans is dependent on the RBC. Our data show that CT density and relative enhancement of clots are independent determinants of clot composition. Using both variables in the CT workup of acute ischemic stroke has the potential to have a decisive impact on patient stratification for treatment.

* Accupaque-350®, GE-Healthcare, Boston, MA, USA.

Accuracy of iodine quantification using dual energy CT in latest generation dual source and dual layer CT

Pelgrim GJ, van Hamersvelt RW, Willemink MJ, et al. Eur Radiol. 2017;27:3904-3912.
https://doi.org/10.1007/s00330-017-4752-9

Thoracic imaging

Purpose

To determine the accuracy of iodine quantification with dual-energy computed tomography (DECT) in two high-end CT systems with different spectral imaging techniques.

Method

- Five tubes with different iodine concentrations (0, 5, 10, 15, 20 mg/ml) were analyzed in an anthropomorphic thoracic phantom.
- Adding two phantom rings simulated increased patient size.
- For third-generation dual source CT (DSCT), tube voltage combinations of 150 Sn and 70, 80, 90, 100 kVp were analyzed. For dual-layer CT (DLCT), 120 and 140 kVp were used.
- Scans were repeated three times.
- Median normalized values and interquartile ranges (IQRs) were calculated for all kVp settings and phantom sizes.

Results

- Correlation between measured and known iodine concentrations was excellent for both systems ($R = 0.999–1.000$, $p < 0.0001$).
- For DSCT, median measurement errors ranged from -0.5% (IQR -2.0, 2.0%) at 150 Sn/70 kVp and -2.3% (IQR -4.0, -0.1%) at 150 Sn/80 kVp to -4.0% (IQR -6.0, -2.8%) at 150 Sn/90 kVp.
- For DLCT, median measurement errors ranged from -3.3% (IQR -4.9, -1.5%) at 140 kVp to -4.6% (IQR -6.0, -3.6%) at 120 kVp.
- Larger phantom sizes increased variability of iodine measurements ($p < 0.05$).

Conclusion

Iodine concentration can be accurately quantified with state-of-the-art DECT systems from different vendors.

Median CT-measured iodine concentration and normalized differences between CT-measured and known iodine concentration are shown for both DSCT and DLCT

	Dual-source CT				Dual-layer CT	
Iodine concentration	150 Sn/70	150 Sn/80	150 Sn/90	150 Sn/100	120 kVp	140 kVp
0 mg/ml (%)	-0.1	-0.1	-0.1	-0.1	0	0
5 mg/ml (%)	4.8 (-4%)	4.8 (-4%)	4.5 (-10%)	4.6 (-8%)	4.5 (-10%)	4.7 (-6%)
10 mg/ml (%)	10.0 (0%)	9.9 (-1%)	9.6 (-4%)	9.8 (-2%)	9.6 (-4%)	9.7 (-3%)
15 mg/ml (%)	15.1 (1%)	15.0 (0%)	14.6 (-3%)	14.8 (-1%)	14.3 (-5%)	14.5 (-3%)
20 mg/ml (%)	19.8 (-1%)	19.3 (-4%)	18.9 (-6%)	19.1 (-5%)	19.3 (-4%)	19.7 (-2%)
Median diff concentration grades mg/ml (%)	-0.1 (-1%)	-0.2 (-2%)	-0.4 (-4%)	-0.2 (-2%)	-0.5 (-5%)	-0.3 (-3%)

Median difference for the separate kVp combinations is shown.

Every scan is a **spectral scan**

The publications in this section demonstrate a major advantage of spectral detector technology on the Philips Spectral detector CT – the availability of spectral information for all patients without the need for prospectively screening the patient to determine if dual-energy mode is needed. Spectral detector CT allows clinicians to acquire true conventional and spectral data simultaneously, in a single scan.

These cases demonstrate the value of not having to pre-determine the need for spectral results. With Spectral detector CT, spectral results are always available to aid in the clinical decision-making process.

Abdominal applications of a novel detector-based spectral detector

Fulton N, et al. Current Problems in Diagnostic Radiology. 2018;47(2):110–118.
http://dx.doi.org/10.1067/j.cpradiol.2017.05.001

Abdominal imaging

Summary

This article provides an overview of SDCT technology in abdominal imaging. Several applications of SDCT in abdominal imaging are discussed and illustrated, along with a brief description of current literature on the status of dual-energy computed tomography in these applications. This includes urinary calculus composition, characterization of masses (renal, adrenal, hepatic and others), tumor perfusion, improving vascular contrast, improving lesion conspicuity, decreasing artifacts and reducing radiation dose.

Conclusion

Spectral detector CT is a novel entrant into the field of spectral CT technology and has several applications in abdominal imaging. A major advantage of this technology is the availability of spectral information on all patients without the need for prospectively screening the patient to determine if the dual-energy mode has to be turned on.

- Effective atomic number and uric acid-calcium pairs are useful in characterizing urinary calculus composition.
- VNC along with iodine maps are useful in characterizing several lesions.
- Iodine maps are also useful in assessing tumor response and response to therapy.
- VMI images are useful in improving vascular contrast and lesion conspicuity at low energy levels and decreasing artifacts such as beam hardening, calcium, and metal at high energy levels.
- VNC images may also eliminate the need for acquisition of true non-contrast images, thus saving radiation dose.

Abdominal applications of detector-based spectral CT

Application	Clinical uses	Type of spectral image used
Urinary calculi composition	Characterize the composition of urinary calculi	- Uric-acid calcium pairs - Effective atomic number
Characterization of masses - Renal - Adrenal - Others	Characterize various lesions - Complicated cyst vs solid renal neoplasm - Adrenal adenoma vs malignancy	- Virtual non-contrast - Iodine map - Effective atomic number
Tumor perfusion response to therapy Improving lesion conspicuity	Detect and quantify lesion perfusion; evaluate the response of tumor to therapy; improve visualization of lesions	- Iodine map - Virtual monoE image (equivalent-energy or low-energy)
Improving vascular contrast	Improve vascular contrast - Boost suboptimal enhanced studies - CTA quality from routine CT abdomen - Low contrast studies	- Virtual monoE image (low-energy)
Decreasing artifacts	- Decrease metallic artifacts - Decrease beam hardening - Decrease motion artifacts	- Virtual monoE image (high-energy) - Iodine map
Radiation dose savings	- By elimination true non-contrast series in multiphasic studies - By avoiding multiple additional studies for lesion characterization	- Virtual non-contrast - Iodine map
Bowel pathology	- Improve detection or absence - Distinguish intra-luminal iodine from ingested material - Distinguish extra-luminal iodine from calcium - Electronic fecal tagging	- Virtual monoE image - Iodine map - Virtual non-contrast

Comparing imaging performance across spectral computed tomography platforms

Sellerer T, et al. RSNA 2017.

Abdominal imaging

Purpose

To evaluate the imaging performance across different spectral CT platforms, including kVp-switching CT, dual-source CT and dual-layer CT.

Method and materials

- A semi-anthropomorphic abdomen phantom for CT performance evaluation was imaged on different spectral CT systems.
  - kVp-switching (Discovery CT750 HD, GE, United States)
  - Dual-source (Somatom Definition Flash & Force, Siemens Healthineers, Germany)
  - Dual-layer CT (Philips Spectral detector CT, Philips Healthcare, the Netherlands)
- Scans were repeated three times for each radiation dose level ($CTDI_{vol}$ 10 mGy, 20 mGy and 30 mGy). To be able to better compare results, all data were reconstructed in a non-iterative mode and dose modulation was switched off.
- The phantom was imaged with different extension rings to simulate obese patients and was equipped with a specific spectral insert, which included the following materials: water-, adipose-, muscle-, liver-, bone-like materials and a variation of iodine concentrations.
- Over the range of available virtual monoE images (VMI) noise, as well as quantitative accuracy of VMI Hounsfield Units (HU), and iodine concentrations were evaluated.

Results

- Over the range of VMI levels, the HUs could be determined with high accuracy when comparing to the theoretical values.
- For kVp-switching and dual-source CT, an increase in noise could be observed towards lower VMI levels.
- A patient size-dependent increase in iodine concentrations error can be observed for all platforms.
- For a medium patient size, the iodine concentration bias was for the three dose levels ($CTDI_{vol}$ 10 mGy, 20 mGy and 30 mGy).
  - 0.344 mg/ml, 0.348 mg/ml and 0.314 mg/ml (kVp-switching).
  - 0.741 mg/ml, 0.736 mg/ml and 0.730 mg/ml (dual-source).
  - 0.240 mg/ml, 0.192 mg/ml, and 0.134 mg/ml (dual-layer).

Conclusion

Iodine concentrations as well as VMI HUs could be accurately determined across different spectral CT systems. In non-iterative reconstruction mode, the noise behavior of dual-layer CT is independent of the keV VMI level, while an increase in noise is observed for kVp-switching and dual-source CT.

Spectral detector CT-derived virtual non-contrast images: comparison of attenuation values with unenhanced CT

Ananthakrishnan L, Rajiah P, Ahn R, et al. Abdom Radiol. 2017;42:702–709.
https://doi.org/10.1007/s00261-016-1036-9

Abdominal imaging

Purpose

To assess virtual non-contrast (VNC) images obtained on a detection-based spectral detector CT scanner and determine how attenuation on VNC images derived from various phases of enhanced CT compares to those obtained from true unenhanced images.

Method

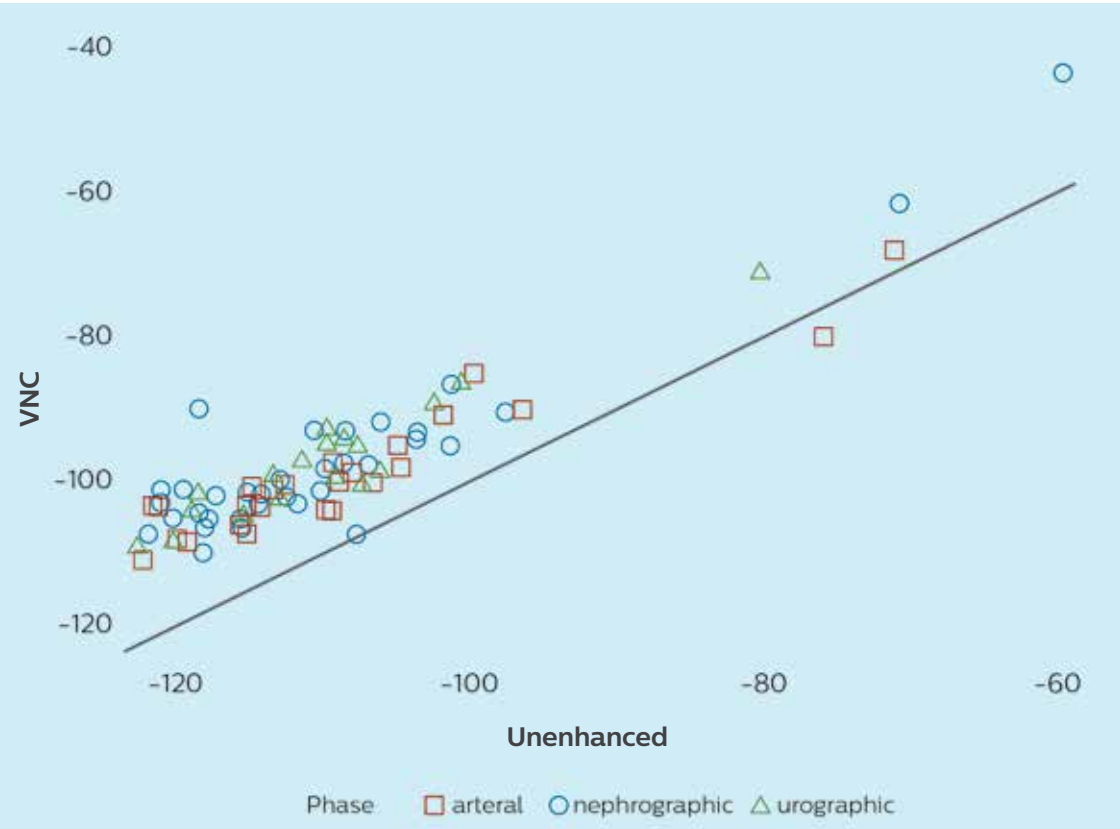
- In this HIPAA-compliant, IRB-approved prospective multi-institutional study, 46 patients underwent pre- and post-contrast imaging on a dual-layer spectral detector CT, yielding 84 unenhanced and VNC pairs (25 arterial, 39 portal venous/nephrographic, 20 urographic).
- Mean attenuation was measured by one of three readers in the liver, spleen, kidneys, psoas muscle, abdominal aorta and subcutaneous fat.
- Equivalence testing was used to determine if the mean difference between unenhanced and VNC attenuation was less than 5, 10, or 15 HU. VNC image quality was assessed on a five-point scale.

Results

- Mean difference between unenhanced and VNC attenuation was <15 HU in 92.6%, <10 HU in 75.2%, and <5 HU in 44.4% of all measurements.
- Unenhanced and VNC attenuation were equivalent in all tissues except fat, using a threshold of <10 HU difference ($p < 0.05$).
- No significant variation was seen between phases.
- In fat, VNC overestimated the HU relative to unenhanced images.
- VNC image quality was rated as excellent or good in 84% of arterial phase and 85% of nephrographic phase cases, but only 40% of urographic phase cases.

Conclusion

VNC images derived from novel dual-layer spectral detector CT demonstrate attenuation values similar to unenhanced images in all tissues evaluated except for subcutaneous fat. Further study is needed to determine if attenuation thresholds currently used clinically for common pathology should be adjusted, particularly for lesions containing fat.



Scatter plot of VNC vs unenhanced attenuation values in subcutaneous fat.

Quantifying metal artifact reduction using virtual monochromatic dual-layer Spectral detector CT imaging in unilateral and bilateral total hip prostheses

Wellenberg RHH, et al. European Journal of Radiology. 2017;88:61–70.
http://dx.doi.org/10.1016/j.ejrad.2017.01.002

Musculoskeletal imaging

Purpose

To quantify the impact of prosthesis material and design on the reduction of metal artifacts in total hip arthroplasties using virtual monochromatic dual-layer detector spectral CT imaging.

Method

- The water-filled total hip arthroplasty phantom was scanned on a novel 128-slice dual-layer scanner (Philips Spectral detector CT) at 120 kVp and 140 kVp at a standard computed tomography dose index of 20.0 mGy.
- Several unilateral and bilateral hip prostheses consisting of different metal alloys were inserted and combined, which were surrounded by 18 hydroxyapatite calcium carbonate pellets representing bone.
- Images were reconstructed with iterative reconstruction and analyzed at monochromatic energies ranging from 40 to 200 keV.
- CT numbers in Hounsfield Units (HU), noise measured as the standard deviation in HU, signal-to-noise ratios (SNRs) and contrast-to-noise ratios (CNRs) were analyzed within fixed regions of interest placed in and around the pellets.

Results

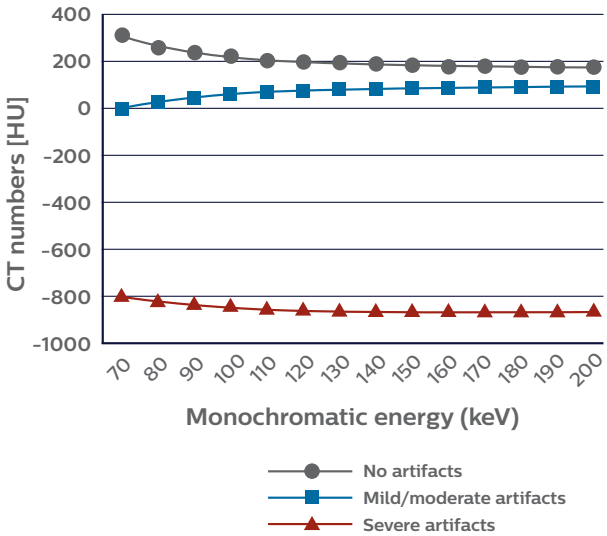
- 130 keV images were optimal for reducing mild to moderate artifacts, based on quantitative analysis of CNRs.
- Optimal keVs varied from 74 to 150 keV for different hip prostheses configurations.
- The titanium alloy resulted in less severe artifacts compared to the cobalt alloy.

Conclusion

Dual-layer detector CT reduces metal artifacts at high monochromatic energies (keV).

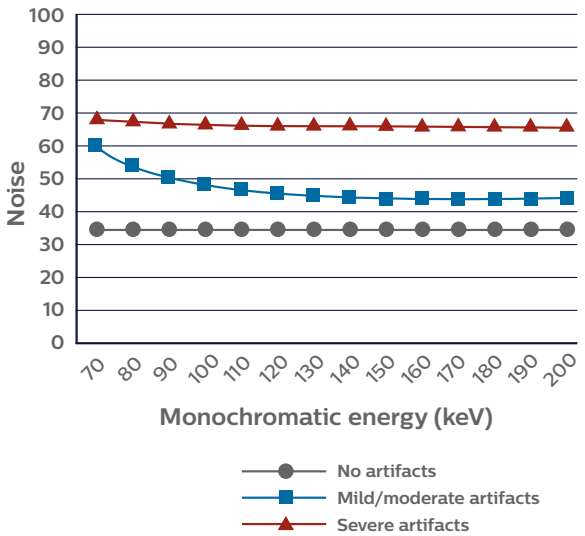
Average CT numbers, noise values, signal-to-noise-ratios (SNRs) and contrast-to-noise-ratios (CNRs) of all pellets categorized as "no artifacts", "mild/moderate artifacts" and "severe artifacts". Virtual monochromatic results from 74 keV up to 200 keV acquired at 140 kVp are shown.

CT Numbers



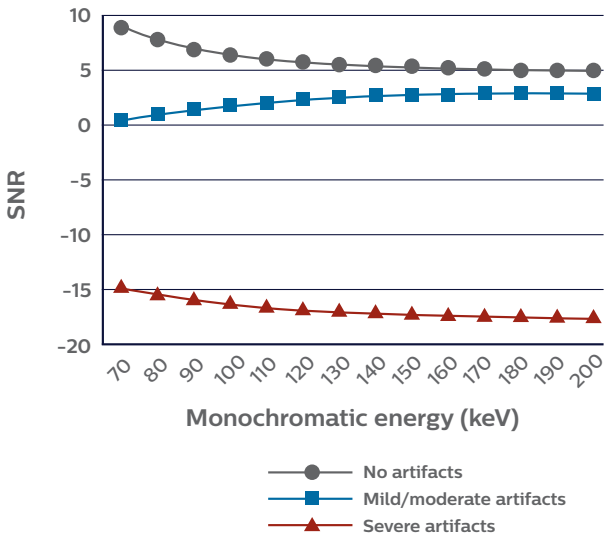
CT numbers of unaffected pellets decreased at high keVs. Also CT numbers of pellets categorized as severe artifacts decreased at high keVs. CT numbers of pellets in mild/moderate artifacts increased with increasing keVs.

Noise values



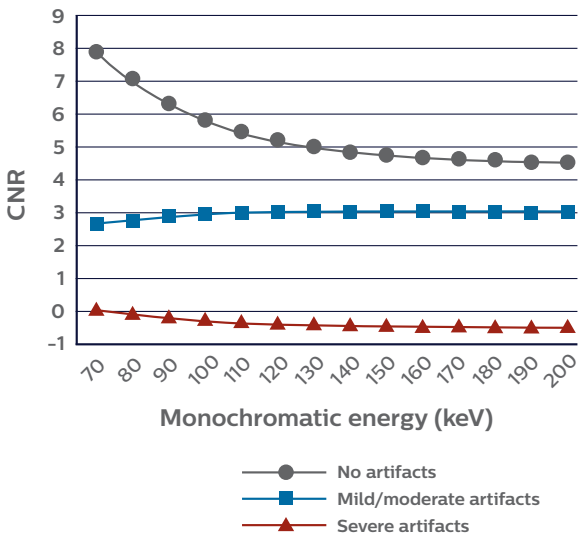
Noise values of unaffected pellets remained constant from 74 up to 200 keV. Noise values of pellets categorized as severe artifacts were high and remained constant. Noise values of pellets in mild/moderate artifacts decreased with increasing keVs.

SNRs



SNRs of unaffected pellets decreased at high keVs. Also, SNRs of pellets categorized as severe artifacts decreased at high keVs. SNRs of pellets in mild/moderate artifacts increased with increasing keVs.

CNRs



CNRs of unaffected pellets decreased at high keVs. Also, CNRs of pellets categorized as severe artifacts decreased at high keVs. CNRs of pellets in mild/moderate artifacts increased with increasing keVs, with a peak CNR of 3.0 at 130 keV.

Metal artifact reduction by dual-layer computed tomography using virtual monoenergetic images

Neuhaus V, et al. European Journal of Radiology. 2017;93:143–148.
http://dx.doi.org/10.1016/j.ejrad.2017.05.013

Musculoskeletal imaging

Purpose

To investigate the performance and diagnostic value of metal artifact reduction in virtual monoE images generated from dual-layer computed tomography (DLCT).

Method

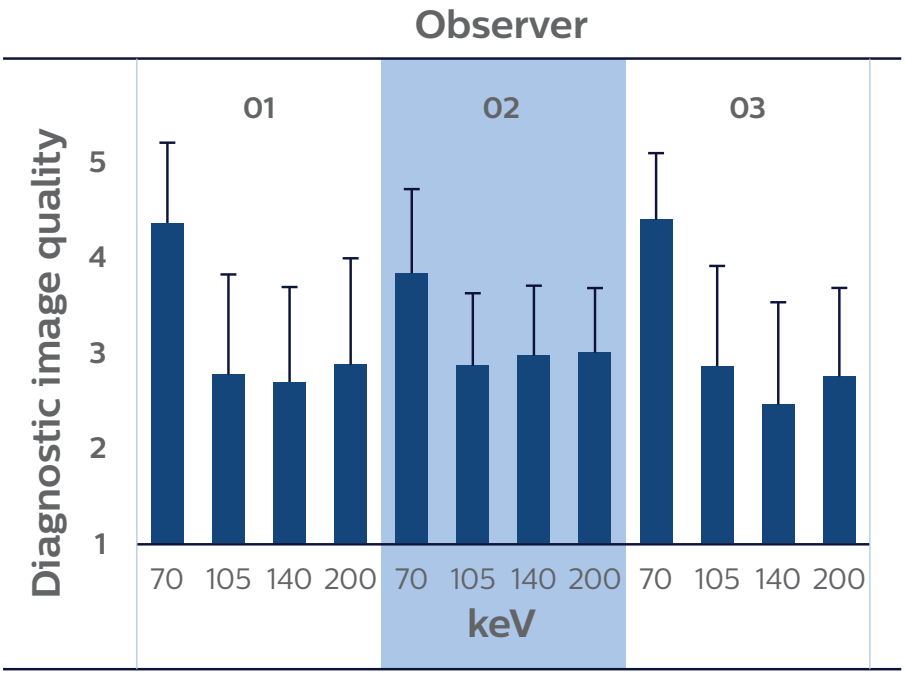
- 35 patients who received a DLCT at the University Hospital Cologne and had an orthopedic implant in the examined region were included in this study.
- For each DLCT, virtual monoE images of different energy levels (64 keV, 70 keV, 105 keV, 140 keV, 200 keV and an optimized photon energy) were reconstructed and analyzed by three blinded observers.
- Images were analyzed with regard to subjective criteria (extent of artifacts, diagnostic image quality) and objective criteria (width and density of artifacts).

Results

- 21 patients had implants in the spine, eight in the pelvis, and six patients in the extremities. Diagnostic image quality improved significantly at high photon energies from a Likert score of 4.3 (± 0.83) to 2.3 (± 1.02), and artifacts decreased significantly from a score of 4.3 (± 0.66) to 2.6 (± 2.57).
- The average optimized photon energy was 149.2 ± 39.4 keV. The density as well as the width of the most pronounced artifacts decreased from -374.6 ± 251.89 HU to -12.5 ± 205.84 HU and from 14.5 ± 8.74 mm to 6.4 ± 10.76 mm, respectively.

Conclusions

- Using virtual monoE images, valuable improvements of diagnostic image quality can be achieved by reduction of artifacts associated with metal implants.
- As preset for virtual monoE images, 140 keV appears to provide optimal artifact reduction.
- In 20% of the patients, individually optimized keV can lead to a further improvement of image quality compared to 140 keV.



Rating of improvement of diagnostic image quality of all three observers (01, 02, and 03) at equivalent keV, 105 keV, 140 keV, 200 keV and optimal keV.

Reduction of artifacts caused by orthopedic hardware in the spine in Spectral detector CT examinations using virtual monoenergetic image reconstructions and metal-artifact-reduction algorithms

Große Hokamp N, Neuhaus V, Abdullayev N, et al. Skeletal Radiol. 2017;47:195–201.
https://doi.org/10.1007/s00256-017-2776-5

Musculoskeletal imaging

Purpose

To assess artifact reduction in patients with orthopedic hardware in the spine as provided by (1) metal artifact reduction algorithms (O-MAR) and (2) virtual monoE images as provided by spectral detector CT (SDCT), compared to conventional iterative reconstruction (CI).

Method

- 128 consecutive patients with orthopedic hardware in the spine who underwent SDCT examinations were included.
- CI, O-MAR, and monoE (40–200 keV) images were reconstructed.
- Attenuation (HU) and noise (SD) were measured in order to calculate signal-to-noise ratio (SNR) of paravertebral muscle and spinal canal.
- Subjective image quality was assessed by two radiologists in terms of image quality and extent of artifact reduction.

Results

- O-MAR and high-keV monoE showed significant decrease of hypodense artifacts in terms of higher attenuation as compared to CI (CI vs O-MAR, 200 keV monoE -396.5 HU, vs –115.2 HU, -48.1 HU; both $p \leq 0.001$)
- Artifacts as depicted by noise were reduced in O-MAR and high-keV monoE as compared to CI in (1) paravertebral muscle and (2) spinal canal — CI vs O-MAR, 200 keV :
  (1) 34.7 ± 19.0 HU, vs 26.4 ± 14.4 HU, $p \leq 0.05$/27.4 ± 16.1, n.s.;
  (2) 103.4 ± 61.3 HU vs 72.6 ± 62.6 HU/60.9 ± 40.1 HU; both $p \leq 0.001$
- Subjectively, both O-MAR and high-keV images yielded an artifact reduction in up to 24/28 patients.

Conclusion

Both O-MAR and high-keV monoE reconstructions as provided by SDCT lead to objective and subjective artifact reduction; thus, the combination of O-MAR and monoE seems promising for further reduction.

Subjective rating of the diagnostic assessment and extent using 5- and 3-point Likert scales

	Diagnostic assessment				Extent on artifacts	
	Metal/bone interface	Spinal canal	Adjacent soft tissue	Noise	Reduction (complete/ moderate/none)	New (yes/no)
CI	3 (1-4)	1.5 (1-2.3)	2 (1.7-3)	3 (2-3)	-	-
O-MAR	3 (2-4)*	1.5 (1-3)*	3 (2-4)*	3 (2-3)	6/16/6	23/28
MonoE						
105 keV	4 (3-5)	2.5 (1.7-3)*	3 (3-4.3)	4 (3-4)	3/10/15	6/28
140 keV	4 (3.7-4)*	3 (2-4)*	4 (3-5)*	4 (3-4)	8/14/6	6/28
200 keV	5 (4-5)*	3 (2-4)*	4 (3-5)*	4 (3-4)*	9/15/4	6/28

* Significant improvements compared to CI ($p \leq 0.05$).

Quality of routine diagnostic abdominal images generated from a novel detector-based spectral CT scanner: a technical report on a phantom and clinical study

Hojjati M, Van Hedent S, Rassouli N, et al. Abdom Radiol. 2017;42:2752–2759.
https://doi.org/10.1007/s00261-017-1170-z

Abdominal imaging

Purpose

To evaluate the image quality of routine diagnostic images generated from a novel spectral detector CT (SDCT) compared to CT images obtained from a conventional scanner with an energy-integrating detector (Brilliance iCT).

Method

- ACR guideline-based phantom evaluations were performed on both SDCT and iCT for CT adult body protocol.
- Retrospective analysis was performed on 50 abdominal CT scans from each scanner.
- Identical ROIs were placed at multiple locations in the abdomen and attenuation, noise, SNR and CNR were measured.
- Subjective image quality analysis on a five-point Likert scale was performed by two readers for enhancement, noise and image quality.

Results

- On phantom studies, the SDCT images met the ACR requirements for CT number and deviation, CNR and effective radiation dose.
- In patients, the qualitative scores were significantly higher for the SDCT than the iCT, including enhancement and quality.
- The SNR was higher in the SDCT than the iCT for liver, spleen, kidney, pancreas and aorta, but was slightly lower in lumbar-vertebra.
- The CNR of the SDCT was also higher than the iCT for all abdominal organs.

Conclusion

Image quality of routine diagnostic images from the SDCT is comparable to images of a conventional CT scanner with energy-integrating detectors, making it suitable for diagnostic purposes.

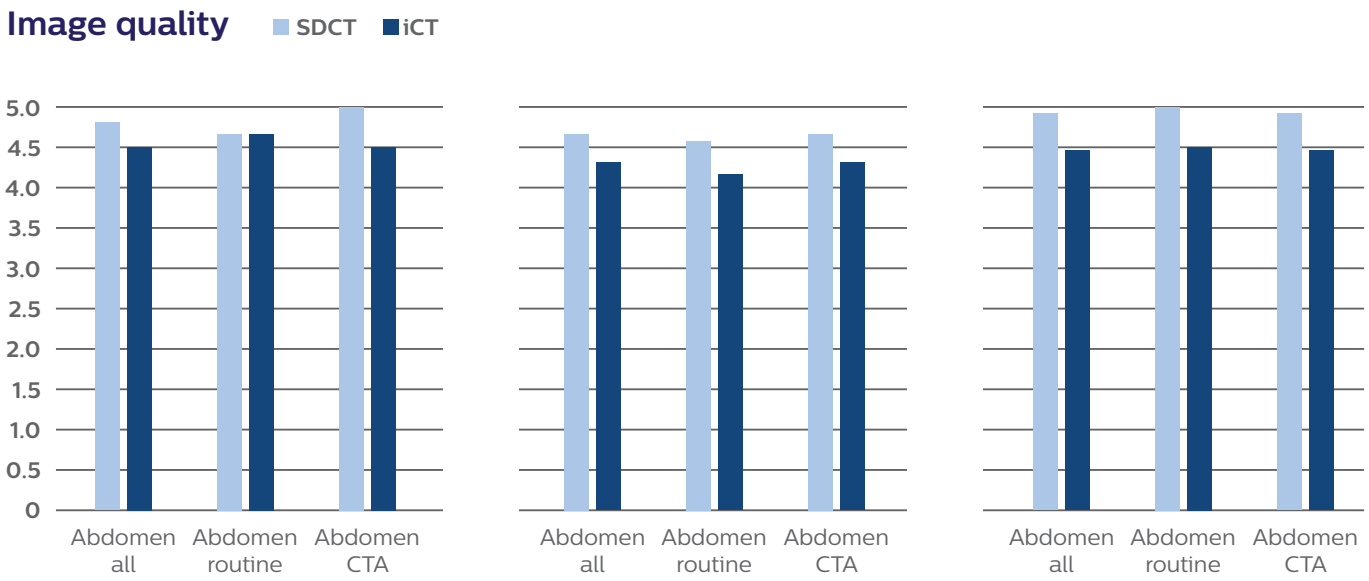


Chart showing the image quality score for different types of CT scans. It can be seen that scores of enhancement, noise and overall image quality are higher in the SDCT than the iCT in all abdominal organs in all the protocols.

Spectral detector CT for cardiovascular applications

Rajiah P, Abbara S, Halliburton SS. Diagnostic and Interventional Radiology. 2017;23(3):187-193.
https://doi.org/10.5152/dir.2016.16255

Cardiac imaging

Summary

This paper provides an overview of SDCT technology and a description of some spectral image types. The potential utility of SDCT for cardiovascular imaging and the impact of this new technology on radiation and contrast dose are discussed through presentation of initial patient studies performed on a SDCT scanner. The value of SDCT for salvaging suboptimal studies, including those with poor contrast-enhancement or beam hardening artifacts, through retrospective reconstruction of spectral data is discussed. Additionally, examples of specific benefits for the evaluation of aortic disease, imaging before transcatheter aortic valve implantation, evaluation of pulmonary veins pre- and post-pulmonary radio frequency ablation, evaluation of coronary artery lumen, assessment of myocardial perfusion, detection of pulmonary embolism and characterization of incidental findings are presented.

Conclusions

- Spectral detector CT is a novel technology that uses two layers of detectors to simultaneously collect low- and high-energy data.
- Virtual monoE images at low energies are useful in improving contrast signal, thus helpful in salvaging suboptimal vascular studies or prospectively using low dose of intravenous contrast.
- Virtual monoE images at high energies are useful in reducing artifacts.
- Spectral detector CT is useful in myocardial perfusion.

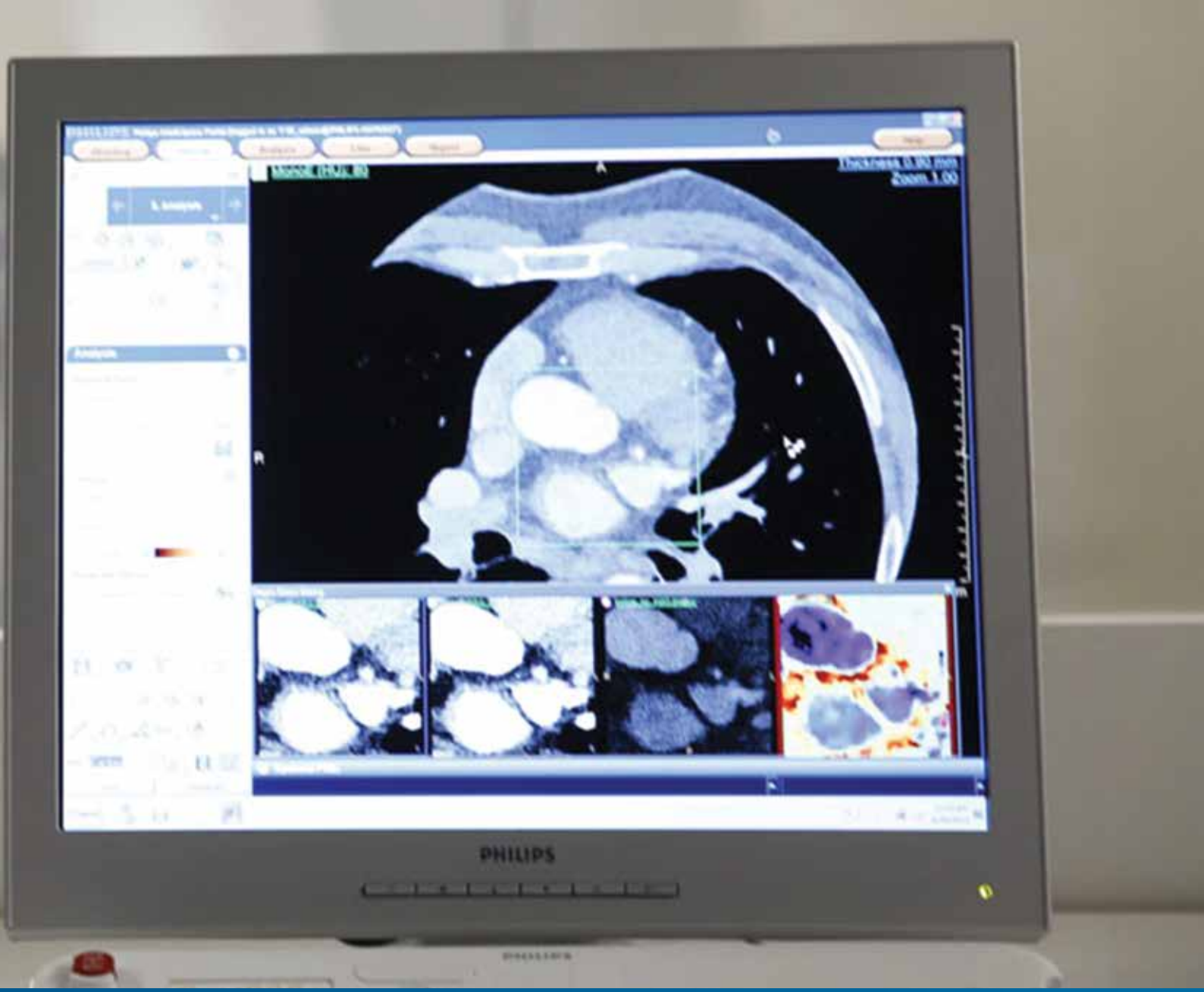
Cardiovascular applications of spectral CT

Application	Clinical uses	Type of spectral image used
Poor contrast enhancement	Boost vascular attenuation in suboptimally enhanced studies; generate CTA quality images from routine contrast CT	Virtual monoE image, low energy
Beam hardening artifacts	Reduce beam hardening artifacts from dense contrast in vein; reduce artifacts from metal	Virtual monoE image, high energy
Evaluation of aortic disease	Eliminate true unenhanced scans by using virtual unenhanced images	Virtual unenhanced
Pre-TAVI (transcatheter aortic valve implantation)	Low contrast dose in patients with renal dysfunction	Virtual monoE image, low energy
Pulmonary vein imaging	Distinguish left atrial appendage thrombus and slow flow	Iodine map
Evaluation of coronary artery lumen	Decrease calcium blooming and improve lumen definition	Virtual monoE image, high energy
Myocardial perfusion	Improve detection of perfusion defects; decrease beam hardening artifacts	Iodine map
Pulmonary embolism	Acute: Improved sensitivity of detection, especially for small defects Chronic: Perfusion abnormalities even in the absence of an obvious clot	Effective atomic number map
Incidental lesion characterization	Characterization of incidental nodules, and masses, particularly in kidneys, adrenals and lungs	Virtual unenhanced, iodine map

Powerful advancements that fit your workflow

The publications summarized here emphasize the advantages of the Philips Spectral detector CT in allowing clinicians to acquire, review and analyze spectral results retrospectively as part of a routine scan.

These studies demonstrate how the ability to read spectral results retrospectively in a routine scan setting helps clinicians achieve clinical benefits and improved diagnostic capabilities.


PHILIPS

Polyenergetic and virtual monoenergetic images from a novel dual-layer spectral detector CT: optimization of window settings is crucial to improve subjective image quality in abdominal CT angiographies

Doerner J, Luetkens JA, Iuga AI, et al. Abdominal Radiology. 2018;43;742–750.
https://doi.org/10.1007/s00261-017-1241-1

Abdominal imaging

Purpose

To determine optimal window settings for polyenergetic (polyE) and virtual monoenergetic images (monoE) derived from abdominal angiographic studies on a novel dual-layer spectral detector CT (SDCT) system.

Method

- From 50 patients, SDCT data sets with polyE and monoE at 70 and 40 keV levels were reconstructed and best individual window width and level (BI-W/L) manually assessed.
- Through regression analysis, the so-called optimized individual (OI-W/L) values were obtained.
- Subjective image quality parameters and vessel diameters were measured to determine influences of different W/L settings.

Results

- Image noise was lower and attenuation and contrast-to-noise ratio were higher in monoE compared to polyE (all $p \leq 0.002$).
- Mean BI-W/L values for polyE (70 and 40 keV) were 637/284, 647/291 and 1568/691, respectively. Mean OI-W/L values were 631/276, 628/286 and 1516/667, respectively.
- Compared to standard settings, all adjusted W/L settings varied significantly and yielded higher subjective scoring.
- No between-group differences were found between manually adjusted and mathematically calculated W/L settings.

Conclusion

PolyE and monoE from abdominal angiographic SDCT studies require appropriate W/L settings, especially at low energy reconstruction levels. Individual adjustment reaches the best image quality but is time-consuming. From our data, predefined W/L settings of 640/280 (polyE/monoE 70 keV) and 1570/690 (monoE 40 keV) as a non-individualized starting point for abdominal angiographic studies from the novel SDCT system are suggested.

Clinical potential of retrospective on-demand spectral analysis using dual-layer spectral detector CT in ischemia complicating small-bowel obstruction

Oda S, et al. Emergency Radiology. 2017;4:431-434.
https://doi.org/10.1007/s10140-017-1511-9

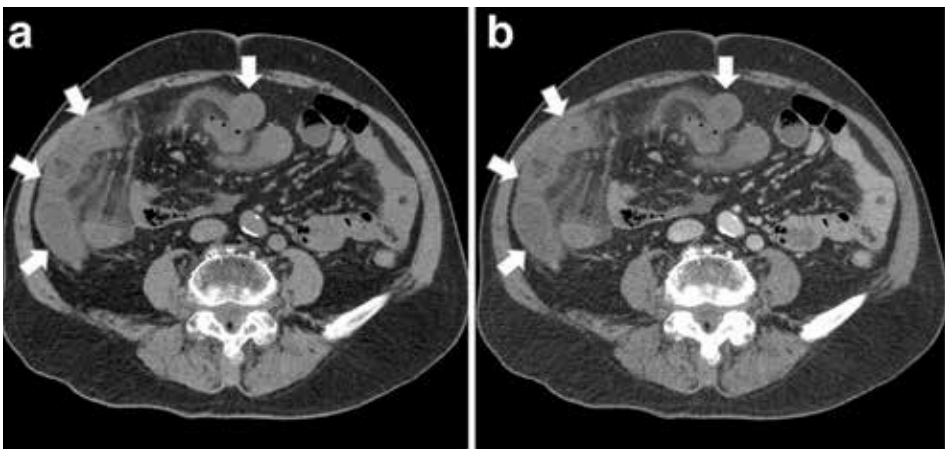
Abdominal imaging

Summary

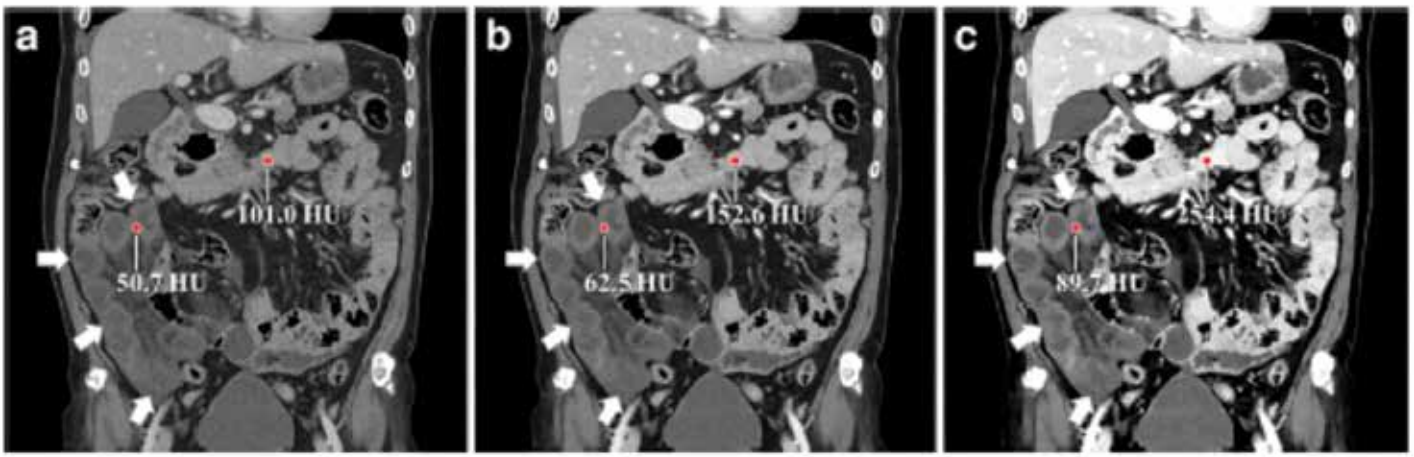
This article describes a case of ischemia complicating acute small-bowel obstruction in which retrospective on-demand spectral analysis using dual-layer spectral detector CT provided the clinician with a higher degree of confidence pertaining to the diagnosis. Dual-layer spectral detector CT enables retrospective on-demand spectral analysis, including virtual monochromatic imaging, iodine mapping and determining the effective atomic number Z, without the need of a pre-scan setting requiring a special protocol, particularly facilitating emergency situations.

Conclusion

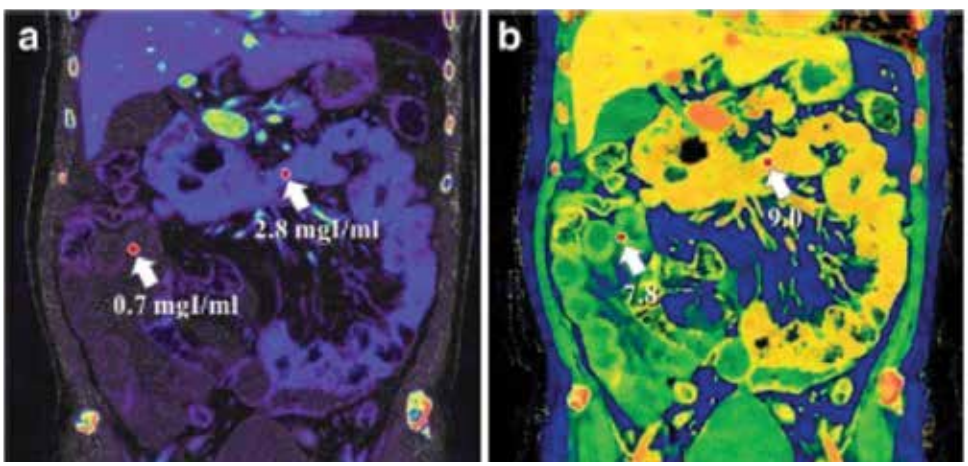
Retrospective on-demand spectral analysis could improve the accuracy and diagnostic confidence in cases with ischemia complicating small-bowel obstruction.



Transverse plain (a) and contrast-enhanced (b) computed tomography images showing small-bowel wall thickening and dilatation, mesenteric stranding, and bowel wall hypo-enhancement in right abdomen (arrows).



Coronal contrast-enhanced CT images showing an ischemic small bowel in the right abdomen (arrows). This hypo-perfused segment is less conspicuous on the conventional image (a) than on the virtual monochromatic images at 55 keV (b) and 40 kev (c). The CT attenuations of the ischemic and non-ischemic segments was 50.7 HU and 101.0 HU at conventional 120 kVp, 62.5 HU and 152.6 HU at 55 keV, and 89.7 HU and 254.4 HU at 40 keV, respectively.



Iodine map showing (a) iodine content of 0.7 mg/ml in a region of interest in the ischemic segment which indicates severe hypo-perfusion, and (b) an iodine content of 2.8 mg/ml in the non-ischemic segment. The effective atomic numbers, Z_{eff}, of the ischemic and non-ischemic segments were 7.8 and 9.0, respectively, which indicates that the non-ischemic segment contains more iodinated contrast than the non-schemic segment.

Assessment of 70 keV virtual monoenergetic spectral images in abdominal CT imaging: a comparison study to conventional polychromatic 120 kVp image

Rassouli N, Chalian H, Rajiah P, et al. Abdominal Radiology. 2017;42:2579–2586.
https://doi.org/10.1007/s00261-017-1151-2

Abdominal imaging

Purpose

To evaluate the image quality of 70 keV virtual monoE abdominal CT images compared to 120 kVp polychromatic images generated from a spectral detector CT (SDCT) scanner.

Method

- This prospective study included generation of a 120-kVp polychromatic dataset and a 70 keV virtual monoE data set after a single contrast-enhanced CT acquisition on a SDCT scanner (Philips Spectral detector CT) during portal venous phase.
- The attenuation values (HU), noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were measured in the liver, spleen, pancreas, kidney, aorta, portal vein and muscle.
- The subjective image quality including noise, soft tissue contrast, sharpness and overall image quality were graded on a five-point Likert scale by two radiologists independently (1=worst image quality, 5=best image quality).
- Statistical analysis was performed using paired sample t-test and Fleiss's Kappa.

Results

- 55 patients (54.3 ± 16.8 y/o; 28 M, 27 F) were recruited.
- The noise of target organs was significantly lower in virtual monoE images in comparison to polychromatic images ($p < 0.001$).
- The SNR and CNR were significantly higher in virtual monoE images ($p < 0.001$ for both).
- Subjective image quality of 70 keV virtual monoE images was significantly better ($p < 0.001$) for all evaluated parameters.
- Median scores for all subjective parameters were 3.0 versus 4.0 for polychromatic vs virtual monoE images, respectively.
- The inter-reader agreement for overall image quality was good (Kappa were 0.767 and 0.762 for polychromatic and virtual monoE images, respectively).

Conclusion

In abdominal imaging, 70 keV virtual monoE CT images demonstrated significantly better noise, SNR, CNR and subjective score as compared to conventional 120 kVp polychromatic images.

Subjective image quality of 70 keV virtual monoE images as compared to conventional 120 kVp polychromatic images

	Poly (median)	MonoE (median)	*p* value
Noise	3	4	< 0.001
Soft tissue contrast	3	4	< 0.001
Sharpness	3	4	< 0.001
Overall image quality	3	4	< 0.001

Reduce costs

With health care moving more towards value-based care, it is essential for hospitals to improve clinical efficiency and reduce duplication of services to make it easier for people to get the care they need. This study demonstrates the ability of Philips Spectral detector CT to scan patients at high risk of CIN with low volumes of contrast – aiding in clinical diagnosis and decreasing the overall imaging costs for these patients by reducing follow-up scans on other modalities.

Spectral detector CT aids radiologists in detection and characterization of lesions

Andersen MB, Ebbesen D, Thygesen J, et al. Impact of spectral body imaging in patients suspected for occult cancer: a prospective study of 503 patients. European Radiology. 2020.
https://doi.org/10.1007/s00330-020-06878-7

Purpose

The purpose of this study was to investigate the clinical impact of spectral detector CT in the detection and characterization of lesions compared to conventional CT.

Method

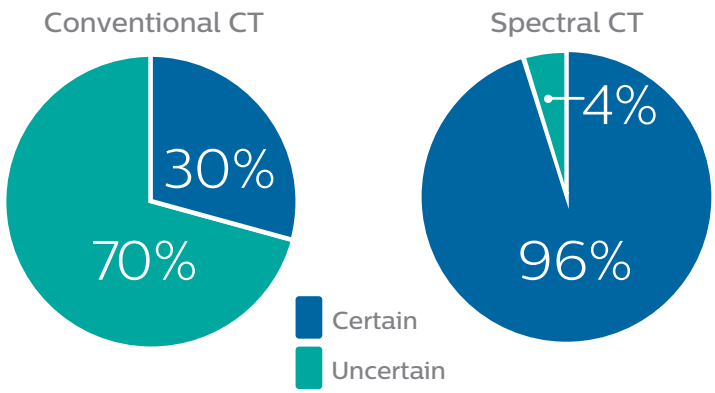
- For this study, a group of 503 patients were prospectively enrolled for a Danish work-up program for patients with unspecific serious symptoms. These patients all received a contrast-enhanced scan acquired on a Philips Spectral detector CT scanner. These scans were retrospectively examined twice; one reading performed on only the conventional data set and one reading with all spectral results available to the radiologist.
- During the reading, the radiologists were able to report up to seven findings per patient. Every finding would receive an assessment of its malignancy, as well as the reader's confidence of the assessment. The readers were also asked to report any additional follow-up examination that they would have requested according to their clinical guidelines. These readings were then compared against the patient outcome after a median of 21 months.

Results

- The follow-up data of the patient population proved a cancer in 15% of the patient population (73 cases). The detection sensitivity of these was significantly higher for spectral detector CT compared to conventional CT (89% vs 77%).
- Although more findings were defined during the spectral reading, the study found a significantly lower number of requested follow-up procedures per reading.
- Apart from detecting more lesions cases, the spectral information also increased the certainty for characterization of benign neoplasms such as cysts and adenomas. For cysts specifically, although detected number of lesions were not significantly different between conventional and spectral CT, the certainty of non-malignancy lesion went up from 30% to 96%, resulting in a decrease of 35% of requested follow-up exams.

Conclusion

Spectral detector CT increases the confidence of radiologists in the characterization of the lesions and reduces the need for follow-up examinations.



Spectral CT increases the certainty for exclusion of malignancy of cysts from 30% to 96%.

Follow-up recommendation rates associated with spectral detector dual-energy CT of the abdomen and pelvis: a retrospective comparison to single-energy CT

Atwi N, et al., Journal of the American College of Radiology. 2020;17(7):940–950.
https://doi.org/10.1016/j.jacr.2019.12.029

Purpose

This study determined if the addition of dual-energy CT (DECT) iodine maps in abdomino-pelvic imaging applications reduces radiologic workup by reducing follow-up imaging recommendations. DECT was performed using the Philips Spectral detector CT.

Method

- Scans were performed between April 2017 and June 2018. Spectral detector CT (SDCT) was used for DECT. Single-energy CT scans were performed on the Philips iCT 256-slice system. SDCT scans of the abdomen and pelvis included 2.5 mm axial plane iodine maps of the portal venous or arterial phase. Iodine density maps allow for easy detection of iodine enhancing structures and quantify the amount of iodine present in the tissue.
- All images were interpreted on PACS by radiologists. Radiology reports were analyzed for follow-up recommendation rates and the specific modality needed for follow-up.

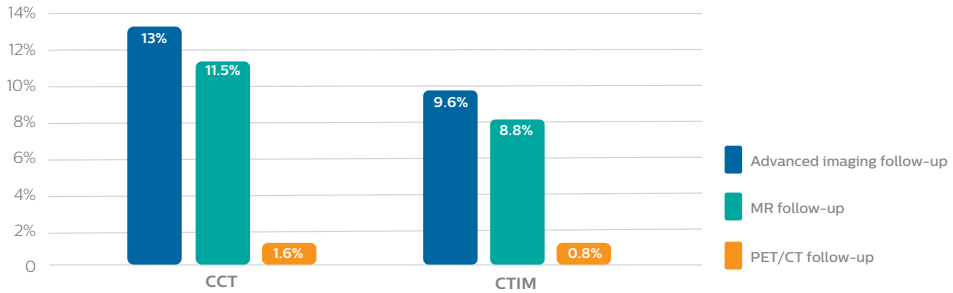
Results

- The rate of recommendation resulting from incomplete diagnosis was significantly higher in CCT (conventional CT) reports as compared to CTIM (CT Iodine Map) reports. CCT reports recommended follow-up due to incomplete diagnosis at a rate of 11.9%, and CTIM reports recommended follow-up due to incomplete diagnosis at a rate of 9.1%.
- The rate of follow-up recommendation for advanced imaging was significantly higher in CCT reports than in CTIM reports. CCT reports recommended advanced imaging follow-up at a rate of 13.0%, and CTIM reports recommended advanced imaging follow-up at a rate of 9.6%.
- CCT reports showed significantly higher MR follow-up recommendation than CTIM reports. CCT reports recommended MR follow-up at a rate of 11.5%, and CTIM reports recommended MR follow-up at a rate of 8.8%.
- The overall follow-up costs were compared between the CCT and CTIM groups using Medicare reimbursement rates. The total cost of follow-up exams resulting from CCT exams was **$465,298.28** and from CTIM exams was **$330,237.84**. The reduction in cost of follow-up scans between CTIM and CCT was **$135,060.44**, resulting in savings of **29%**.

Conclusion

Iodine maps generated by DECT, when used as part of routine radiology workflow, are associated with lower rates of recommendation for additional radiology studies due to incomplete diagnosis or characterization. This result suggests that incorporating iodine maps into the radiologist's workflow increases diagnostic confidence and aids in classification of incidental findings while significantly reducing costs associated with follow-up exams.

Follow-up recommendation rates from incomplete diagnosis



Economic impact of spectral detector CT for patients with renal insufficiency

Norwood D, et al. Philips. 2017.

Purpose

To evaluate the impact of spectral detector CT (SDCT) scanning with low volumes of contrast on the time to achieve clinical diagnosis and overall imaging costs for patients with high risk of CIN due to low eGFR.

Method

- A total of 60 patients were divided into two groups:
  - Group 1 consisted of 30 patients with reduced renal function (based on eGFR values) scanned without contrast on a Philips iCT scanner.
  - Group 2 consisted of 30 patients with reduced renal function scanned with 50-80 cc of contrast scanned on the Philips Spectral detector CT. Scanning protocol for Group 2 was the same as Group 1.
- In both groups, CT scans were obtained for head-neck, chest-abdomen-pelvis, or head-neck combined with chest-abdomen-pelvis. Most patients were scanned for an oncology evaluation, either initial diagnostic scans or therapy follow-up exams.
- A retrospective data review on PACS and electronic management of records (EMR) was also performed to evaluate the number of follow-up scans received by patients in Group 1 and Group 2 over a period of three months. The dates of the original and follow-up scans on other modalities were recorded to calculate the time to final diagnosis.

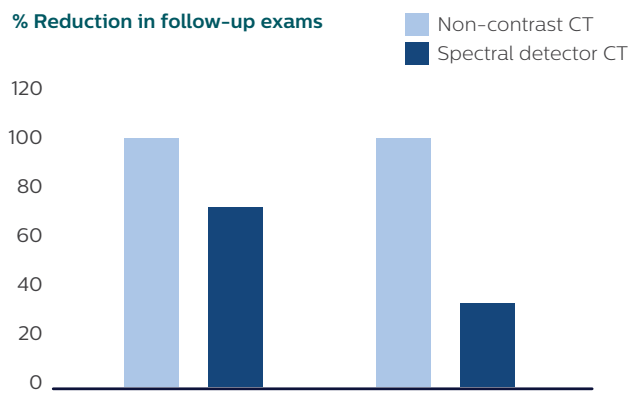
Results

- The analysis revealed that the 30 patients who received a non-contrast CT would need additional diagnostic tests – an additional follow-up MRI and two ultrasound scans within a period of three months.

  This would result in additional average cost of $453 per follow-up scan in patients using non-contrast CT, as compared to the group of patients scanned on Philips Spectral detector CT.*
- Contrast-enhanced scans on the SDCT reduced the time to diagnosis of those patients from 100 days to 66 days. This is a 34% reduction in time to diagnosis.

Conclusion

- The use of SDCT allows scanning of patients with high risk for CIN using iodinated contrast.
- The use of contrast on these patients improves the clinician's ability to identify and delineate lesions and structures in solid organs such as liver, kidney, pancreas, neck, brain, etc., thereby reducing the need for follow-up exams.
- Collectively, Philips Spectral detector CT allows scanning on an expanded patient population and enables contrast-enhanced scanning on a patient population that would not have been eligible to receive contrast. This reduces the time to diagnosis by 34%, also reducing the need for additional follow-up scans for this sub-group of patient population.



*Based on CMS.gov, Coding and Revenue Resource Center,

Summary

The cases summarized in this compendium show evidence that having spectral results available for a variety of clinical indications can help improve the diagnostic decision-making process.

The Philips Spectral detector CT allows for retrospective reconstruction of spectral results, and provides the physician with enhanced diagnostic capabilities, even in patients who would not have been pre-selected for a spectral scan. Having spectral results available for every patient scanned on the Spectral detector CT provides clinicians with the reassurance that if more data is needed to increase diagnostic confidence for a clinical exam, it is readily available anytime, virtually anywhere – demonstrating the value that the Spectral detector CT brings to imaging.

References

1. Sher A, Ghandour A, Rajiah P. Evaluation of Monochromatic Energy Reconstruction on Pulmonary Angiography Using Spectral Detector CT. RSNA 2014.

2. Sher A, Ghandour A, Rong R, Rajiah P. Evaluating Optimal Monochromatic Energy Reconstruction on Aortic Angiography Obtained from Spectral Detector CT. RSNA 2014.

3. Chalian H, Mansoori B, Chalian M, Rajiah P. Salvage of Suboptimal CT Angiographic Studies Using Virtual Monoenergetic Images from Novel Spectral Detector CT Scanner. RSNA 2015.

4. Ben-David E, Gomori JM, Leichter I, Romman Z, Sosna J. Accuracy of Carotid In-Stent Stenosis Measurement in a Phantom Model Using Effective Atomic Number Imaging Produced by Dual-Layer Dual-Energy CT. RSNA 2015.

5. DiPoce J, Sosna J, Shaham D, Romman Z, Goldberg N. Spot the Clot: Improvements in CT Detection of Thrombus Using an In Vitro Dual-Energy Based Phantom Model. RSNA 2015.

6. Rong R, Rios C, Li F, Rajiah P, Landeras L. Spectral Detector Computed Tomography (Dual-Layer CT): Clinical Applications in Thoracic Imaging. RSNA 2014.

7. Rajiah P. Musculoskeletal Applications of Spectral CT – Principles, Physics and Clinical Applications. RSNA 2015.

8. Rajiah P. Genitourinary Applications of Spectral CT. RSNA 2015.

9. DiPoce J, Romman Z, Sosna J. Optimal Energy for Kidney Parenchymal Visualization in Monoenergetic Images Generated from Dual-Energy CT. RSNA 2015.

References

10. Chailan M, Sher A, Eck B, Wilson D, Gilkeson R, Bezerra H, Rajiah P. Cardiovascular Applications of Spectral CT Using Single-Source Dual-Layer Detector Technique. RSNA 2014.

11. Leichter I, Lipschuetz T, Vichter T, Romman Z, Sosna J. Automatic Quantification of Iodine and Calcium Using Monoenergetic Virtual Images Generated by Spectral Detector Dual-Layer CT: A Phantom Study. RSNA 2015.

12. Chalian M, Mansoori B, Chalian H, Rajiah P. Effect of Calcium Blooming in Coronary Arteries at Different Monoenergetic Levels of a Novel Spectral Detector CT and Comparison with Polyenergetic Conventional Image. RSNA 2015.

13. Fahmi R, Eck B, Levi J, Fares A, Dhanantwari A, Vembar M, Bezerra H, Wilson D. Dynamic Myocardial Perfusion in a Porcine Ischemia Model Using Spectral Detector CT. RSNA 2014.

14. Rajiah P. Cardiothoracic Applications of Spectral CT – Physics, Principles and Clinical Applications. RSNA 2015.

15. Rajiah P. Applications of Spectral CT in Neuroimaging. RSNA 2015.

16. Rong R, Rios C, Li F, Rajiah P, Landeras L. Spectral Detector Computed Tomography (Dual-Layer CT): Initial Experience in Abdominal Imaging. RSNA 2014

Notes

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