Spectral CT with Deep Intelligence: Chest Imaging in a Brilliant Light

Jay Vaishnav, Ph.D.
Clinical Scientist and Senior Manager
CT Medical Affairs
Canon Medical Systems USA, Inc.

Adell May, R.T.(R)(M)(CT)(MR)
Clinical Development Manager
CT Medical Affairs
Canon Medical Systems USA, Inc.

Thoracic Imaging: From Single Energy to Spectral

Computed tomography (CT) is a central modality in thoracic radiology. CT pulmonary angiography is the reference standard investigation for diagnosis of acute pulmonary embolism, and chest CT has many other indications ranging from characterization of lung nodules to airway diseases to interstitial lung diseases.

Multi-energy imaging has further expanded the clinical utility of chest CT. While conventional single energy CT provides information about anatomical structure, multi-energy CT offers increased ability to differentiate materials and characterize tissues. Multi-energy CT helps visualize iodine—iodine maps can assist physicians in detecting contrast enhancement or differences in local perfusion, as well as differentiating iodine from calcium. Iodine mapping is particularly relevant in chest CT, where IV contrast helps visualize mediastinal and vascular structures, chronic pleural disease, and lung masses, as well as helping differentiate parenchyma from the pleura or pleural collections.[1]

Multi-energy CT is the only technology permitting the direct comparison of two CT angiograms of a patient obtained at different energy spectra and after contrast administration, acquired nearly simultaneously and with similar hemodynamic conditions. This capability permits multi-energy CT to provide functional information on perfusion and ventilation. The combination of morphological and functional information allows for comprehensive evaluation of lung disease.[2,3,4,5] Multi-energy CT has proven useful in the diagnosis of acute and chronic pulmonary emboli (PEs), other vascular disorders, lung malignancies, and parenchymal diseases, as well as in oncologic applications.[4,6]

To bring the power of multi-energy CT to routine patient care, Canon Medical is introducing rapid kV switching Spectral CT with Deep Learning Reconstruction, launched with the Aquilion ONE / PRISM Edition.

Canon Medical's Spectral CT solution uses rapid kV switching technology. A single X-ray source toggles

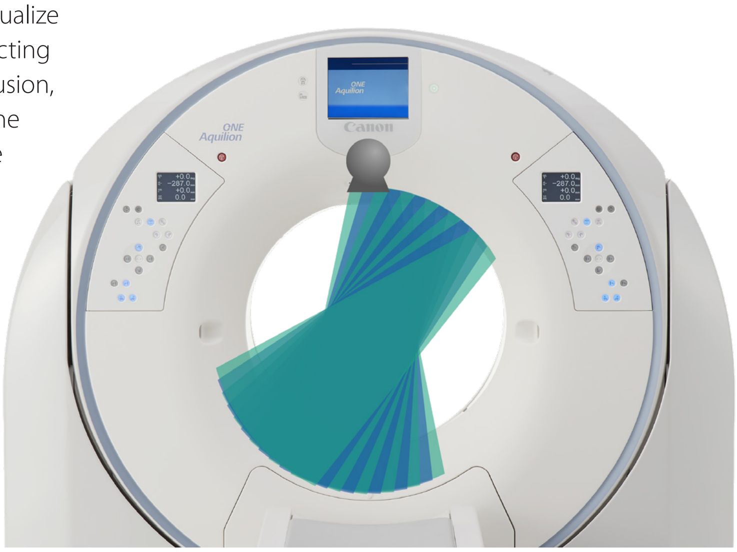

Figure 1 The Aquilion ONE / PRISM Edition implements spectral imaging via rapid kV switching.

between 80 and 135 kVp at sub-millisecond speed, generating a set of interleaved views of data from the two kVp settings. The use of rapid kV switching enables the acquisition of nearly simultaneous and spatially aligned X-ray projections through the patient, minimizing the impact of gantry motion and involuntary patient motion.

The Aquilion ONE / PRISM Edition offers spectral CT with

- Full anatomical coverage of up to 50 cm in-plane. This full field of view can cover peripheral lung lesions in large patients that might not be visible with smaller fields of view.
- Coverage of up to 16 cm in the longitudinal direction; in pediatric imaging, 16 cm can be sufficient coverage to cover the entire thorax in a single rotation.

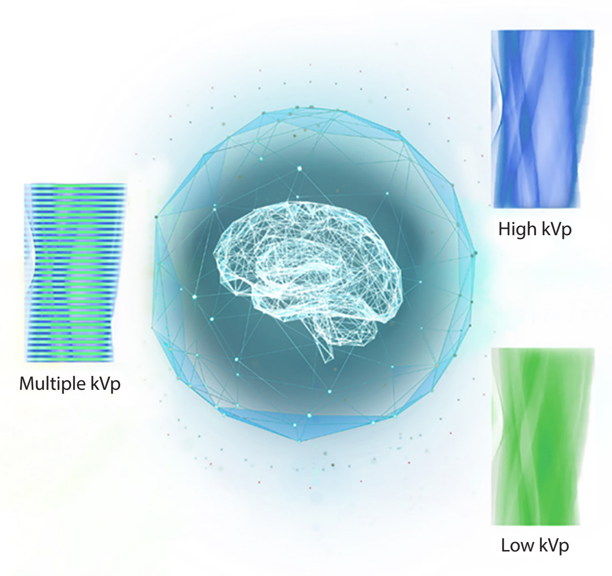

Figure 2 The Aquilion ONE / PRISM Edition's deep learning spectral algorithm trains at Canon's factory, on thousands of complete low and high kVp data sets. Using that knowledge, the algorithm learns how to expand the single interleaved multi-energy raw data set into two full low and high energy data sets, an intermediate step toward generating the final spectral images.

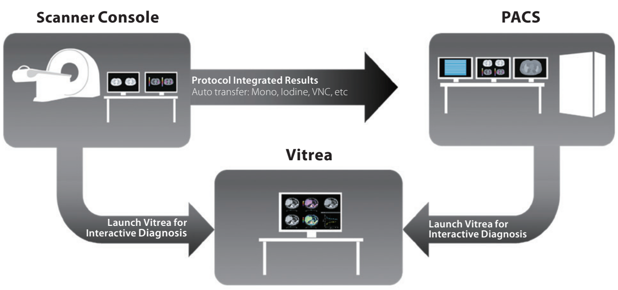

Figure 3 The combination of automatic transfer of images from the scanner to PACS with the interactive applications on Vitrea provides full flexibility to support any user workflow.

- Raw data based material decomposition, possible because of rapid kV switching technology and less impacted by beam hardening than image based postprocessing.[7]
- Patient-specific automatic exposure control, suitable for routine use with spectral CT. Optimizing dose in chest imaging is important to patient care, particularly as the chest includes the radiosensitive lung and glandular breast tissue.

Integrating Imaging with Intelligence

Canon Medical has integrated deep learning technology throughout the process of generating spectral images.

Rapid kV switching technology generates interleaved projection data at low and high kVp. Multi-energy CT requires generating two complete sinograms of raw data. To obtain these complete sinograms, Canon's Spectral reconstruction uses deep learning to perform an intermediate step internal to the algorithm, expanding the interleaved views into two complete datasets that each effectively come from a single kVp source (Fig. 2). Leveraging the similarity between anatomical structures in the low and high kVp data sets, the algorithm uses data from each of the energy sets to create additional "deep learning views" (DLVs) for the other. The deep learning algorithm trains to do this at Canon's factory, on thousands of sets of phantom and patient data.

The use of DLVs results in a high degree of temporal and spatial alignment of the projection data. In multi-energy CT, this alignment of projection data is important for minimizing temporal artifacts and accurately classifying materials. The use of DLVs also permits Spectral CT to offer 16 cm coverage in the longitudinal direction, and 50 cm in-plane.

Automated Workflow

To help make Spectral imaging easy for routine use, Canon's Spectral imaging solution offers automated workflow. The Spectral Imaging solution offers automatically generated monochromatic images, material specific reconstructions, and iodine maps—requiring no extra effort or training for the technologist. Images go directly to the reading station, with quantitative analysis available on dedicated spectral applications in Vitrea™.

Spectral CT automatically generates virtual monochromatic images at 101 energy levels (35–135 keV), providing an additional dimension for interpreting CT examinations.

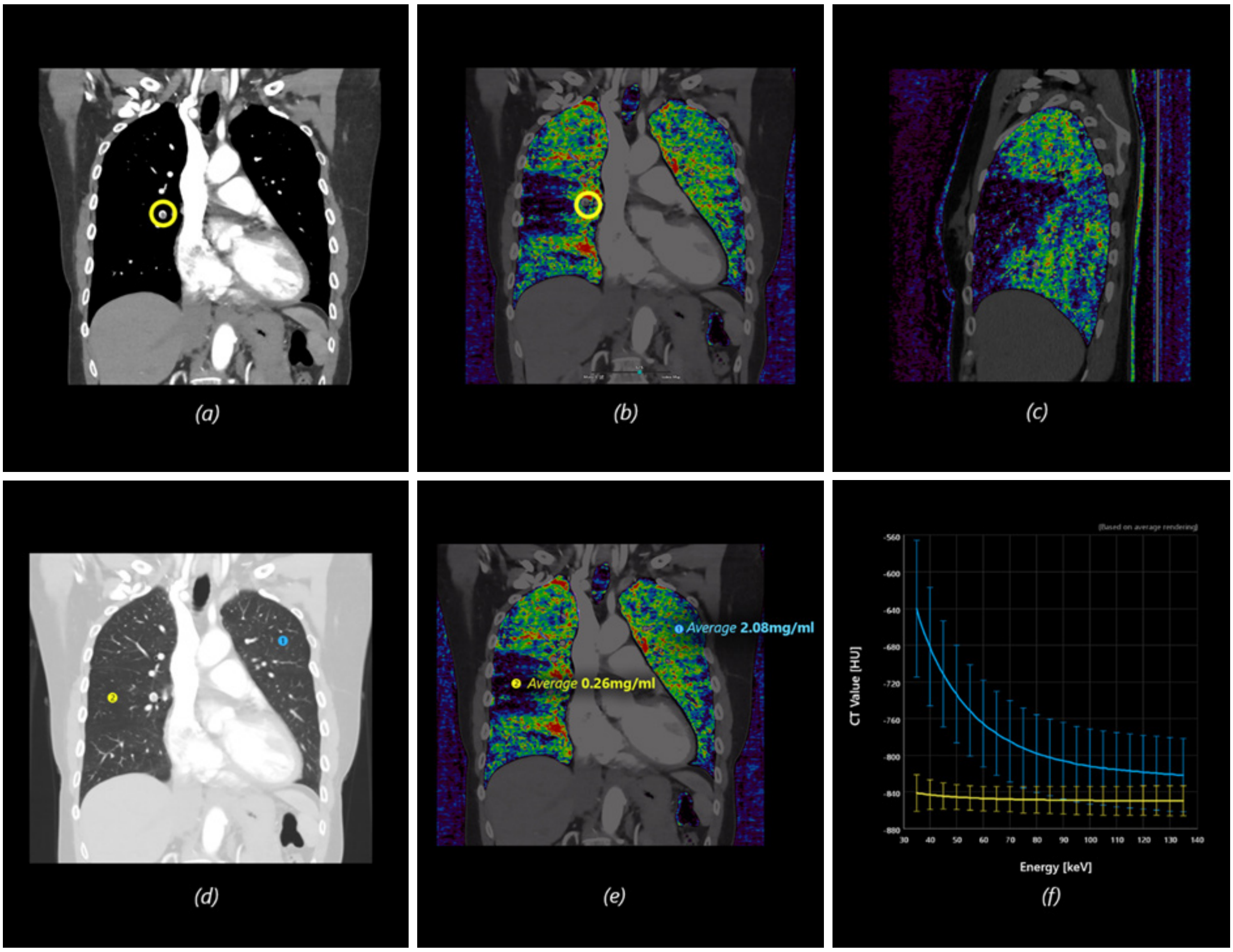

Figure 4 Pulmonary embolism. This patient presented with shortness of breath. On the 70 keV image **(a)**, a pulmonary thrombus is visible in the right pulmonary arteries (yellow circle). In the iodine map fusion images **(b-c)**, a wedge-shaped hypoperfusion region is visible, with the thrombus site at the apex. The pulmonary embolus is more prominent on the iodine map than on the 70 keV monochromatic image—the iodine map thus provides supporting information for, and can serve as a check on the original image. **(d)** The ROI in the monochromatic image (lung windows) shows average HU values. On the iodine fusion map **(e)**, the ROI shows the average Iodine concentration (mg/ml). The spectral curve **(f)** characterizes material by showing the variation of the HU value across the 101 energy levels available on the monochromatic spectrum. The yellow curve does not vary much with keV, consistent with a relative absence of iodinated contrast media in the yellow ROI. The blue curve indicates increased enhancement of the blue ROI at low keVs, characteristic of iodine.

Acquisition: Spectral Helical, CTDI 8.9 mGy, 4.5 mSv (k = 0.014)

Thoracic Imaging

The Aquilion ONE / PRISM Edition with Deep Learning Spectral offers:

- Automatic reconstruction of virtual monochromatic images
- Material specific reconstructions, including virtual unenhanced images
- Generation of iodine maps—concentration of iodine in the lung relates to pulmonary blood volume.

The Aquilion ONE / PRISM Edition also offers the generation of spectral curves, basis material analysis, electron density, and effective Z maps.

Here are some examples of these features at work in thoracic imaging:

Perfusion Defect due to Parenchymal Disease—Pulmonary Embolism

Pulmonary embolism is the third leading cause of death in the USA.[8] In 2007, pulmonary CT angiography was accepted as the reference standard for diagnosis of acute PE;[4] however, single energy CT angiography only provides morphological information, and its ability to assess small segmental and subsegmental emboli is known to be limited.[9]

Fig. 4(a) shows a virtual monochromatic image at 70 keV. While the pulmonary embolus inside the yellow ROI is visible, it is more prominent on the iodine maps in Figs. 4(b-c), where the perfusion defect is apparent as a large wedge-shaped region of hypoperfusion. This example illustrates the benefits of Spectral CT: Spectral CT provides functional information that complements morphological information.

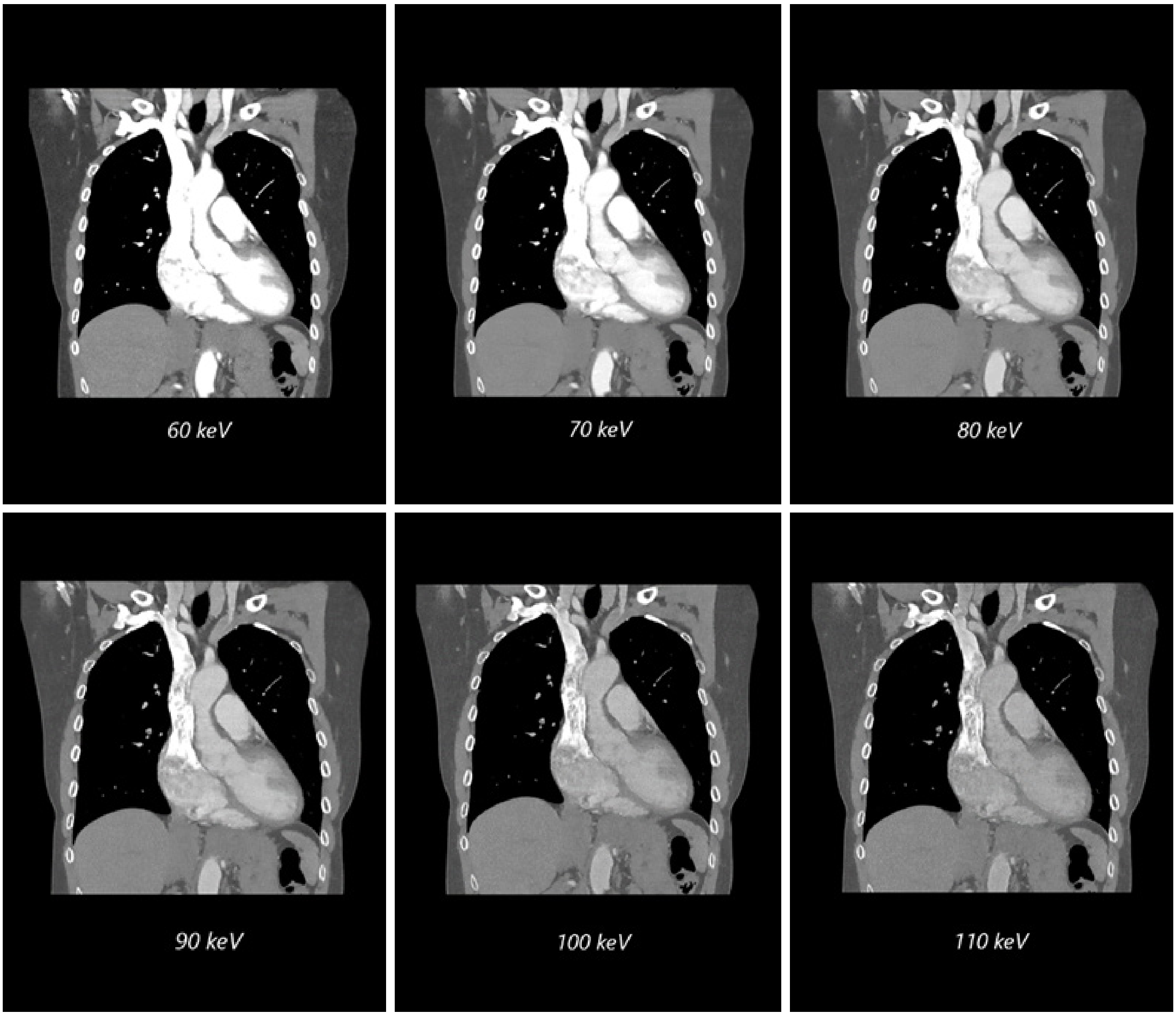

Figure 5 Pulmonary thromboembolism, virtual monochromatic images. Spectral CT allows the generation of virtual monochromatic images for the 101 energy levels between 35 and 135 keV. Spectral CT allows easy tuning of the energy to suppress or enhance contrast, or optimize the contrast difference between two adjacent structures.

Acquisition: Spectral Helical, CTDI 8.9 mGy, effective dose 4.5 mSv (k = 0.014)

Fig. 5 shows how the use of virtual monochromatic imaging can suppress or enhance the appearance of IV contrast.

Solitary Pulmonary Nodule

Solitary pulmonary nodules (SPNs) under 3 cm in diameter are the most common initial manifestation of lung cancer,[10] making their diagnostic evaluation important. While conventional contrast-enhanced CT gives information about the morphology and enhancement of nodules, that information is frequently insufficient to distinguish benign nodules from malignant ones. Multi-energy CT can measure additional characteristics of SPNs.

For example, from a single scan, Deep Learning Spectral CT can provide virtual monochromatic images (Figs. 6a-6b), as well as iodine maps and overlays (Figs. 6c-d). The iodine maps improve visibility of nodules with iodine uptake.

Additionally, Spectral Imaging delivers sufficient energy separation and sufficiently low noise to enable quantitative assessment of an SPN's iodine uptake (Fig. 6d), as well the generation of spectral curves (Fig. 6e). While conventional CT can only identify a nodule's CT number at the average photon energy, with Deep Learning Spectral Imaging, for a given ROI, a user can generate an entire spectral HU curve showing the variation of a nodule's CT number across the full range of monochromatic energy levels. The contrast curves of benign inflammatory and malignant masses can be different, because their blood supply is different.[11]

The information that Deep Learning Spectral Imaging offers can help facilitate assessment of benign vs. malignant lesions.

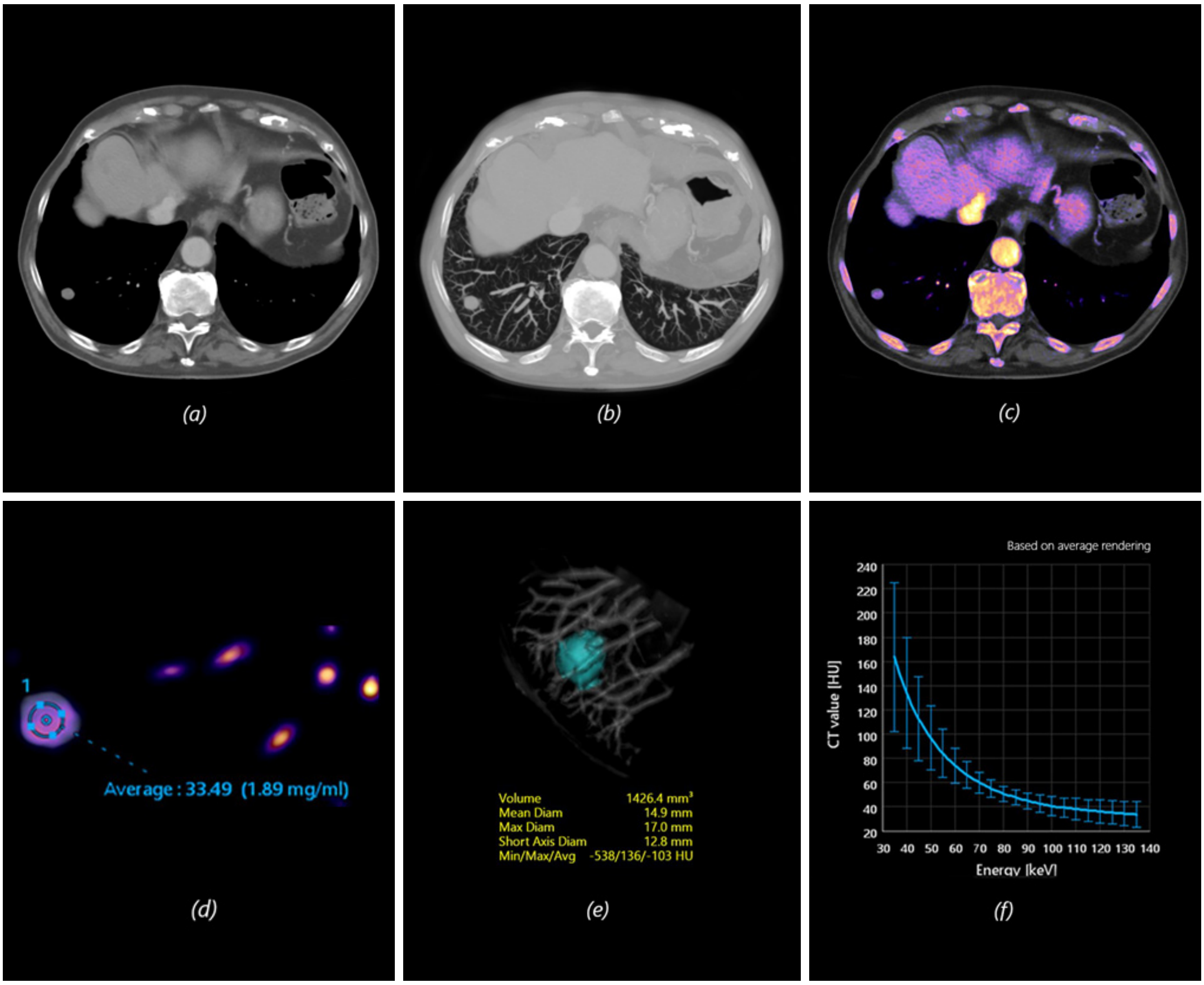

Figure 6 Solitary pulmonary nodules under 3 cm in diameter are the most common initial manifestation of lung cancer.[10] From a single scan, Deep Learning Spectral CT can generate virtual monochromatic images. **(Figs. 6a-6b)** with tunable keV, as well as iodine maps and overlays. **(Fig. 6c)** The low noise properties of Spectral DLR enable quantification of the lesion's iodine uptake. **(Fig. 6d)** and generation of a contrast curve **(Fig. 6e)** Contrast curves show the uptake of the nodule at different monochromatic energy levels, adding a new dimension of information to information about nodule characterization.

Acquisition: Spectral Helical, CTDI 7.4 mGy, effective dose 7.6 mSv (k = 0.014)

Summary

CT is a mainstay of thoracic imaging. By adding the ability to obtain functional as well as structural information from images, multi-energy CT expanded the capabilities of CT. The Aquilion ONE / PRISM Edition offers spectral imaging based on the integration of deep learning with rapid kV switching technology. This combination allows a full 50 cm field of view in-plane, up to 16 cm of coverage in the longitudinal direction, rapid kV switching, and the routine use of patient-specific automatic exposure control. This is an important tool for optimizing dose that has not always been compatible with CT technology. In chest imaging, dose optimization is particularly important due to the presence of radiosensitive organs like the lung and glandular breast.

Canon's Spectral CT solution combines artificial intelligence with the power of rapid kV switching technology to deliver crisp iodine maps and low noise properties, enabling quantification of iodine as well as generation of spectral curves. As illustrated by the examples of a pulmonary embolism and a solitary pulmonary nodule, these features add extra dimensions of information to common clinical tasks in thoracic imaging. New advanced applications on the Vitrea platform offer workflow efficiency, helping bring Spectral protocols to routine use.

Combining the features of spectral imaging with the power of deep intelligence, Canon's Spectral Imaging solution enables physicians to see the chest in a brilliant light.

References:

1. P. Whiting, N. Singatullina and J. Rosser, "Computed tomography of the chest: I. Basic principles," *BJA Education*, vol. 15, no. 6, p. 299, 2015.
2. J. Ko, S. Brandman, J. Stember and D. Naidich, "Dual-energy computed tomography: concepts, performance, and thoracic applications," *J Thorac Imaging*, vol. 27, pp. 7-22, 2012.
3. R. Kaza, J. Platt, R. Cohan, E. Caoili, M. Al-Hawary and A. Wasnik, "Dual-energy CT with single- and dual-source scanners: current applications in evaluating the genitourinary tract.," *RadioGraphics*, vol. 32, pp. 353–369, 2012.
4. M. Kang, C. Park, C. Lee, J. Goo and H. Lee, "Dual-energy CT: clinical applications in various pulmonary diseases," *RadioGraphics*, vol. 30, pp. 685–698, 2010.
5. H. Wu, J. Cheng, J. Li, Y. Yin, J. Hua and J. Xu, "Pulmonary embolism detection and characterization through quantitative iodine-based material decomposition images with spectral computed tomography imaging," *Invest Radiol.*, pp. 47:85–91, 2012.
6. G. M. Lu, Y. Zhao, L. J. Zhang and U. J. Schoepf, "Dual-Energy CT of the Lung," *American Journal of Roentgenology*, vol. 199, pp. S40-S53, 2012.
7. B. Li, G. Yadava and J. Hsieh, "Quantification of Head and Body CTDIvol of Dual-Energy X-Ray CT With fast-kVp Switching," *Medical Physics*, vol. 38, no. 5, p. 2595, 2011.
8. T. Laack and D. Goyal, "Pulmonary Embolism: An Unsuspected Killer," *Emerg Med Clin North Am.*, p. 961, 2004.
9. A. Moore, J. Wachsmann, M. Chamarthy, L. Panjikaran, Y. Tanabe and P. Rajiah, "Imaging of acute pulmonary embolism: an update.," *Cardiovasc Diagn Ther.*, vol. 8, no. 3, p. 225, 2018.
10. P. Pisani, F. Bray and D. Parkin, "Estimates of the world-wide prevalence of cancer for 25 sites in the adult population," *Int J Cancer*, vol. 97, pp. 72–81, 2002.
11. Y. Zhang, J. Cheng, X. Hua, M. Yu, C. Xu, F. Zhang, J. Xu and H. Wu, "Can Spectral CT Imaging Improve the Differentiation between Malignant and Benign Solitary Pulmonary Nodules?," *PLoS One*, vol. 11, no. 2, p. e0147537, 2016.
12. E. Baerends, L. J. Oostveen, C. T. Smit, M. Das, I. Sechopoulos, M. Brink, F. D. Lange and M. Prokop, "Comparing dual energy CT and subtraction CT on a phantom: which one provides the best contrast in iodine maps for sub-centimetre details?," *Eur Radiol*, vol. 28, no. 12, pp. 5051-5059, 2018.
13. J. J. Erasmus, J. E. Connolly, H. P. McAdams, and V. L. Roggli, "Solitary pulmonary nodules: Part I. Morphologic evaluation for differentiation of benign and malignant lesions," *Radiographics*, vol. 20, no. 1, pp. 43-58, 2000.

CANON MEDICAL SYSTEMS USA, INC.

https://us.medical.canon

2441 Michelle Drive, Tustin, CA 92780 | 800.421.1968

Model number: TSX-306A

CTWP13660US MWPCT0007EB

Made For life