Spectral CT: A Brave New World of Quantitative, Functional Imaging

CT has long been considered an excellent method for viewing high-resolution images of human anatomy in a non-invasive manner. It has been used in conjunction with PET and MRI—devices that can image tissue and organ function—to bring together anatomic and morphologic information for a more precise patient diagnosis and treatment plan.

While CT is “an excellent technique with good spatial and temporal resolution, the soft tissue contrast and ability to discriminate normal and pathological tissues is sometimes inferior to other imaging techniques,” says Valentin Sinitsyn, MD, PhD, Chief of the Radiology Department at the Federal Center of Medicine and Rehabilitation (Moscow) and Professor and Chair of Radiology, School of Fundamental Medicine at Moscow State University. This limitation has led to the utilization of other functional imaging techniques in conjunction with CT imaging—which may result in additional studies and potentially higher healthcare costs.

However, CT is closing the gap between anatomical and alternative functional imaging thanks to advances in spectral CT and the introduction of Gemstone® Spectral Imaging (GSI) on the Discovery® CT750 HD scanner. Today, GSI is beginning to change the way radiologists across the world utilize CT imaging.

“GSI’s spectral HU curve and material-basis analysis provides us with information on material characterization and quantification—this is revolutionary.”

– Prof. Xiao-Peng Zhang
**GEMSTONE SPECTRAL IMAGING**

**Gemstone Spectral Imaging**

Gemstone Spectral Imaging (GSI) is a dual-energy scan mode that acquires data of an object by rapidly switching between low kVp and high kVp energies in less than half a millisecond. This generates data with different attenuation values based on the corresponding energy levels. The result is a near-perfect, simultaneous dual-energy acquisition at the full 50 cm scan field of view (SFOV) producing projection (raw) data at two different energy levels that has virtually no misregistration. This enables raw data-based reconstruction of dual-energy data with the associated benefits of quantitative material decomposition and beam-hardening reduction from monochromatic energy synthesis.

Projection-based reconstruction is used to process the data. Based on known attenuation curves, the process mathematically transforms low and high kVp attenuation measurements into effective material density (MD) basis-pair images. This is also known as material decomposition. GSI produces these MD pairs which are not available with conventional contrast-enhanced CT imaging. The make-up or composition of the MD pairs can be selected based on the clinical question being investigated and materials of interest, such as iodine-water, iodine-calcium, or water-calcium.

GSI also produces a monochromatic image, which is synthesized from the MD images and depicts how the object would look if the X-ray source produced only X-ray photons at a single energy.

Specific tools have been created in the GSI Viewer to support the data analysis of this rich information. Tissue characterization can be aided with the help of Hounsfield unit (HU) spectral curves; metal artifact reduction is enabled by interactively switching to the optimal monochromatic energy level. Additionally, material identification is made possible by displaying the effective atomic number histograms of objects, particularly kidney stones.

“GSI is breaking down a barrier by bringing a new type of functional imaging to CT,” explains Jean-Nicolas Dacher, MD, PhD, Professor of Radiology and Diagnostic Imaging and the Chief of the Department of Diagnostic Imaging at Rouen University Hospital (France). He routinely uses GSI, performing approximately 20 cases each week. “Plus, with CT we have the advantage of a quick examination that can be more comfortable for the patient,” he adds. This is compared to traditional functional imaging studies (MR, SPECT and PET) that can last a minimum of 20 minutes to one hour, an important consideration for very sick and elderly patients.

After conducting more than 1,500 GSI scans and 20 pilot studies in the first three months of using GSI, Xiao-Peng Zhang, MD, Professor and Chairman of Radiology, Peking University Cancer Hospital and Institute (China), clearly sees its clinical value. “We believe GSI will change the way that doctors practice and interpret CT,” he says. “GSI’s spectral HU curve and material-basis analysis provide us with information on material characterization and quantification—this is revolutionary.”

Revolutionary is a statement echoed by Lawrence Tanenbaum, MD, FACR, Director of MRI, CT, and Outpatient/Advanced Development, Mt. Sinai School of Medicine (USA). “Spectral CT offers potentially revolutionary information when compared to traditional polychromatic CT,” he says, “including the ability to reduce certain artifacts, such as streak and beam hardening from metal, enhance contrast resolution that will perhaps make iodine more or less conspicuous, or improve contrast resolution by alternating energy levels to differentiate two different tissues.”

**Tissue characterization**

GSI enhances tissue characterization through its ability to derive images that separate materials such as calcium, iodine, and water.

“What really impresses me is the rich tissue characterization capability of spectral CT,” says Dr. Tanenbaum. “To look at a dense brain lesion and know whether it is hemorrhagic, enhancing or calcified is very helpful, particularly in difficult case scenarios.”

The 101 selectable energies and monochromatic images of GSI, explains Prof. Zhang, enable easier and clearer detection of extremely tiny structures—for example, the pancreatic duct and membranous structures such as the greater omentum. “This is rarely achieved using conventional CT,” he adds.

“With the GSI-generated iodine maps, I can clearly see the severity of perfusion deficit.”

– Prof. Valentin Sinitsyn
Pulmonary embolism

GSI represents what is lacking in a typical CT study, says Prof. Sinitsyn. After the Discovery CT750 HD scanner with GSI was installed at the Federal Center in November 2009, he immediately began investigations on pulmonary emboli.

“Traditionally, CT provided an excellent depiction of the pulmonary vessels, thrombi and emboli,” he explains. “However, it could not give us full information on the severity of pulmonary embolism obstruction or perfusion deficit defects. With the GSI-generated iodine maps, I can clearly see the severity of perfusion deficit.”

Upon closer review, Prof. Sinitsyn discovered he could also detect tiny thrombus or embolus inside the pulmonary artery, which often causes the perfusion defect.

“In patients with chronic embolism,” he adds, “it is clear that if we see multiple perfusion defects there exists a strong indication to support surgical removal of the thrombi.” He cites a recent study where the occurrence and severity of the perfusion defect as determined by spectral CT is a strong predictor of patient prognosis.

Prof. Dacher also uses GSI on a daily basis to generate iodine maps for lung perfusion studies (by centering the images on the iodine). Most exciting, he says, is the capability to view the pulmonary artery anatomy for helping to detect clots at the same time he obtains a lung perfusion map. He can then use the anatomical and functional information—obtained during the same study—to assess the pulmonary emboli. “It is very interesting to see there is no match between the extension of the pulmonary embolus and the pulmonary perfusion abnormality,” he explains.

In one particularly interesting case at the University Hospital of Rouen, pulmonary embolus was suspected in a patient presenting with chest pain. Prof. Dacher performed a GSI study and discovered the pulmonary artery was encased by a tumor. “The flow was limited and there was hypo perfusion that was completely obvious on the GSI study because we could see the anatomy and function,” he explains. “If we had performed only scintigraphy—historically the exam of choice for these cases—we would have only noted the reduced perfusion of the upper lobe.” This could have resulted in an incorrect diagnosis of pulmonary embolism and possibly led to the patient unnecessarily receiving an anticoagulant, he explains.

Figure 1A. A GSI iodine map depicts a wedge-shaped perfusion defect in the 9th segment of the left lung.

Figure 1B. A small embolus inside the corresponding segmental branch of the left pulmonary artery can be seen with GSI.
“GSI is not simply a new study area, rather it is changing the way we think and practice CT imaging.”

– Prof. Xiao-Peng Zhang

Oncology
For Prof. Zhang, the most significant use of spectral CT is to quantitatively characterize lesions via the spectral HU curve, which graphically displays the attenuation characteristic of a region across all 101 spectral energies.

“Using the monochromatic images, we can visualize anatomic and internal structures of lesions, which is important for early detection,” says Prof. Zhang. He finds the material characterization and quantification very useful in helping him identify different types of lesions and diseases, and gaining information on cancer at different stages.

Additionally, GSI provides rich and reliable hemodynamic information of tissue with iodine quantification. “It helps us accurately identify infiltrated areas with the iodine-based images,” adds Prof. Zhang, “and with a reliable method to evaluate hemodynamic status, we can evaluate therapy results more confidently.”

Lymphoma

Figure 2A. Affected lymph node of the neck.

Figure 2B. Affected lymph node of the porta pulmonis.

Figure 2C. Affected lymph node of the mediastina.

Figure 2D. Affected node of the spleen.
One clinical question that a traditional CT exam cannot answer is whether or not a lesion enhances. This is often evaluated in terms of Hounsfield units, explains Prof. Sinitsyn. Yet the value assigned may not be precise, as the enhancement may be partially due to beam hardening artifact or artificially inflated via image processing. “When I see a small enhancement, I may not be able to determine if it is true or artificial,” he says. “By comparing water and iodine images, I get the information to quantify the area of interest based on the accumulation of iodine and objectively determine if the lesion is a concern that requires follow-up.”

Renal stones

Prof. Sinitsyn also uses GSI to assess renal stones. Often, where there is one kidney stone, there are more, so it is important to know the material composition. “GSI can help quantify the renal stone, whether it is a calcified stone or predominantly a soft stone containing uric acid,” he says. The latter can be treated with techniques other than surgery, Prof. Sinitsyn adds.

Figure 3. Spectral HU curves show the same pattern of different affected lymph nodes in the same patient with lymphoma, which indicate these lymph nodes are of the same nature as lymphoma.
Reducing artifact

With the continued increase in metal instrumentation—hip and knee prosthesis and spinal fusion, for example—the issue of artifact degrading image quality is becoming more pronounced, explains Dr. Tanenbaum. Reducing these artifacts is an important benefit that GSI provides in his daily practice.

“Between 33% and 40% of our routine spine exams involve instrumentation,” he says.

Figure 4. Note the lack of metal artifact in patient with spinal instrumentation in the 110 keV image on the right compared to the 70 keV image on the left.
Traditional techniques are challenged by implanted metal hardware, leading to images with beam hardening and streak artifacts.

“Spectral CT generates virtually pristine images in these most challenging circumstances where traditional techniques often fail,” Dr. Tanenbaum adds. “We can restore the information in areas that were previously deteriorated by artifact and thus, substantially improve the imaging results in these difficult cases.”

Recently at the European Congress of Radiology (ECR) 2011 annual meeting, Prof. Dacher presented a study demonstrating that he could more easily obtain high quality images of the femoral arteries in patients with metallic hip prosthesis by using GSI. “We cannot accept limitations in the investigation of the femoral artery, so this may be a strong advantage of GSI.”

Enhancing contrast resolution

Iodine-based contrast material used in CT imaging is very well suited to being manipulated—either enhanced or eliminated, explains Dr. Tanenbaum. “Not only can we make the iodine more useful, but it provides an opportunity to deal with sub-optimal contrast administration,” he adds.

Radiologists can either make the contrast more conspicuous in the image by adjusting the energy or create a material-based image that eliminates visibility of the contrast. “With this capability, we have additional information in situations where, historically, we’ve performed both a non-contrast and post-contrast CT study,” Dr. Tanenbaum adds.

Prof. Dacher also sees an opportunity to use GSI in cases where optimal opacification (contrast enhancement) is not ideal, particularly in older patients or those without good venous access. “When we acquire images with GSI, it is possible to decrease keV and enhance the small amount of contrast media in the patient vessel.”

“Spectral CT generates virtually pristine images in these most challenging circumstances where traditional techniques often fail.”

– Dr. Lawrence Tanenbaum
“We cannot accept limitations in the investigation of the femoral artery, so this may be a strong advantage of GSI.”

– Prof. Jean-Nicolas Dacher
Changing clinical pathways

Within one year of using GSI at the University Hospital of Rouen, Prof. Dacher and his colleagues have changed their clinical protocols. “For pulmonary embolisms, metallic prosthesis, and pulmonary hypertension cases, we first utilize CT with GSI,” he says. “In lung perfusion, we have replaced scintigraphy—and in some cases MRA—with a spectral CT exam.” The advantage of CT, he adds, is the speed of the exam and relative patient comfort—both important considerations when evaluating very ill or elderly patients.

“What really impresses me,” Prof. Dacher says, “is the ability to quantify the amount of iodine within a voxel. This is a technical breakthrough that will continue to become more important in medicine.”

At Mt. Sinai, GSI is now a routine study on patients with instrumented spines or in neuroradiology cases when the radiologist suspects the presence of an aneurysm clip. “Spectral CT improves the quality of some of our most challenging exams,” Dr. Tanenbaum says, “and it certainly has an impact on the information I can provide for surgical planning purposes.”

The additional information generated by GSI “helps with deciding the course of treatment for the individual patient, in particular whether it should be more conservative or aggressive,” explains Prof. Sinitsyn. He sees the potential to eliminate additional studies with the ability to quantify areas of interest while providing an objective and accurate diagnosis.

“Dual-energy will further increase the significance of CT, including when and where we use it,” he adds. It is his hope that the continued use of spectral CT will enable the implementation of an objective, quantitative measurement of CT data—in other words, moving away from Hounsfield units to the use of effective atomic numbers or something similar.

Driven by an RSNA initiative, the aim of the radiology community is seeking to be more quantitative in imaging, explains Dr. Tanenbaum. Leveraging this capability of spectral CT should impact positively in the characterization of disease and be useful for surveillance of patients. “It clearly gives us rich, more quantitative information than we had before,” explains Dr. Tanenbaum. “We are only touching the surface of future possibilities—it remains to be seen with widespread implementation and clinical imagination where spectral CT will lead us.”

What it really comes down to is whether spectral CT will raise the level of diagnostic confidence and reduce the reliance on multi-modality testing resulting from inconclusive exams.

“GSI is not simply a new study area. Rather, it is changing the way we think and practice CT imaging,” adds Prof. Zhang. “It advances CT to an entirely new level and opens up a brave new world for the pioneer who embraces the spirit of discovery.”

Continuing enhancements to GSI

Thanks to the collaboration of clinical leaders such as Prof. Dacher, Prof. Sinitsyn, Dr. Tanenbaum, and Prof. Zhang, GE Healthcare continues to refine GSI. Although Prof. Dacher has limited experience with the next iteration of GSI Viewer, he notes that it provides faster reconstruction speed and the ability to generate MIPs and MPRs. Both Prof. Dacher and Prof. Zhang see the potential to further reduce patient exposure to dose, leading to greater utilization of the technique.