Whitepaper

True Enhance DL

Introduction

Gemstone Spectral Imaging (GSI), with ultra-fast kV switching, has been in clinical use since its release in 2009. GSI has been shown to improve image quality over conventional imaging techniques due to higher contrast-to-noise ratio (CNR), reduced beam-hardening artifacts, enhanced material separation, and more accurate and quantitative material information [1]. Since then, academic research and clinical exploration of GSI have grown rapidly and resulted in the publishing of multiple scientific papers as well as effective clinical adoption. In 2017, GSI expanded to RevolutionTM CT, newly named as GSI Xtream due to additional features and functionality. Such as, X-ray tube with 3x faster kV switching capable as compared to Revolution HD , high voltage generator, Gemstone Clarity Detector, enhanced image reconstruction algorithms, with a simplified workflow[2]. These new capabilities enhanced routine GSI clinical tasks significantly, improving diagnostic quality. Over the last four years, GSI has continued progressing via synchronized kV and mA switching with the new Quantix 160 X-ray tube [3], and deep learning based denoising algorithm technology (TrueFidelity with GSI). This allowed for expanded clinical utilization across various patient sizes in some cases with dose levels comparable to single energy scans.

Monochromatic Images on GSI Xtream

Monochromatic images, ranging from 40 to 140 keV, depict objects as if they were imaged with a theoretical monochromatic beam whose X-ray energy is measured in kiloelectron volts (keV) instead of peak kilovoltage (kVp). Monochromatic images in GSI are synthetically generated by the decomposed basis material pair data through dual energy material decomposition theory. Here, the key quality factors are the spectral induced behaviors management under polychromatic X-ray use in clinical CT systems. Among them, the top three important factors are spectral calibration, beam hardening, and scatter management. GSI Xtream utilizes advanced spectral calibration including heel effect management, the projection domain material decomposition process, and a 3D hardware collimator with Gemstone Clarity Detector. Therefore, the CT HU number behavior on GSI Xtream monochromatic images follows linear attenuation coefficient properties of monochromatic keV energies.

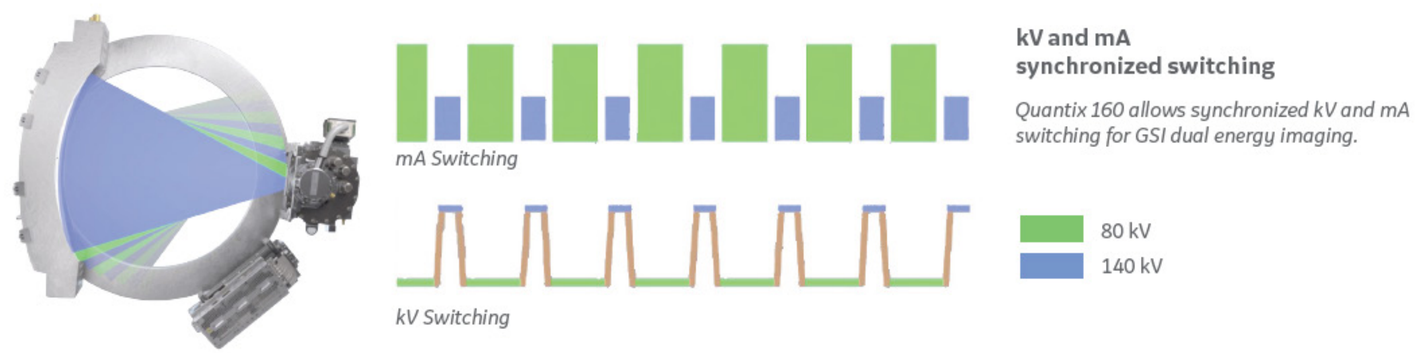


Figure 1: GSI Xtream with Quantix 160 X-ray on Revolution Apex platform

Monochromatic Images – clinical benefits

This monochromatic imaging has been widely used in daily clinical procedures with the unique capability of the specific keV based energy image generation between 40 to 140 keV. The lower keV image such as, 40-60 keV, tend to have higher contrast for iodine-based contrast enhanced area and bony structure. The benefit of this is shown in Fig.1, where you see improved carcinoma mass visibility in 50 keV compared to 70 keV image.

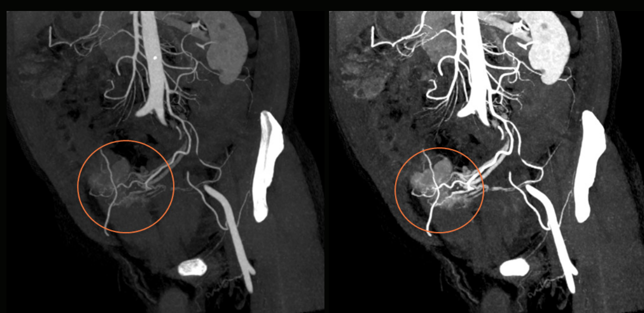


Figure 2: Clinical example of GSI Monochromatic keV imaging (left: 70 keV, right: 50 keV) 50 keV image shows higher visual contrast at the iodine-based contrast enhanced areas at colon carcinoma mass.

These technical advancements have increased the demand of dual energy imaging in various clinical situations; however, such high-performance scanners require specific scan data acquisition hardware and heavy computational power which increase cost, thus the capability has been limited to the flagship scanner segment and has not expanded to all other CT scanner segments as of yet.

Deep learning technology, a subset of Artificial Intelligence (AI)

Another remarkable technological advancement is in Deep Learning (DL) technology, a subset of Artificial intelligence (AI). DL technology has gained significant popularity in recent years because of advances in GPU computational power and the development of modern algorithms for network topology from efficient training. The power of DL lies in its ability to handle complex models and a vast number of parameters far beyond the abilities of human engineers and scientists [5,6]. GE HealthCare developed and released deep learning image reconstruction, also known as TrueFidelity Images in 2019, the first company in industry to launch such a technology [4]. It has yielded outstanding image quality similar to reconstruction methods such as Model-Based Image Reconstruction (MBIR), and Adaptive Statistical Image Reconstruction algorithms (ASiR, ASiR-V) but with classic image texture similar to the Filtered Back Projection (FBP) images radiologists are familiar with reading. This DL-based reconstruction algorithm had a profound impact on not only CT image reconstruction field but also entire CT market. Generally, Deep Neural Network (DNN) training requires significant computational calculations; however, the unique benefit is once DNN is built, its inferencing process is reasonably faster. Utilizing this unique feature, deep learning image reconstruction was able to flow-down to 64-slice/40-mm scanners rapidly.

True Enhance DL's image generation engine combines high quality GSI monochromatic images with cutting-edge AI technology

In the clinical use of GSI, Monochromatic 70 keV has typically been the primary image series used in diagnosis due to its comparable image contrast and noise texture quality of 120 kVp conventional images [7-9], whereas, 50 keV has been used as the desired iodine-based contrast enhanced image quality[10,11]. The latest version of GSI Xtream on RevolutionTM Apex has simultaneous dual energy acquisition, projection-based multi-material beam hardening reduction, and corrected material decomposition to generates accurate and consistent monochromatic images across multiple keV ranges. The idea behind True Enhance DL was to utilize high quality monochromatic images generated by GSI dual energy imaging as a target in training. True Enhance DL models were trained in supervised learning sessions to transform GSI monochromatic 70 keV images into images that are comparable to GSI monochromatic 50 keV images. The training and inference scheme is shown in Figure 3.

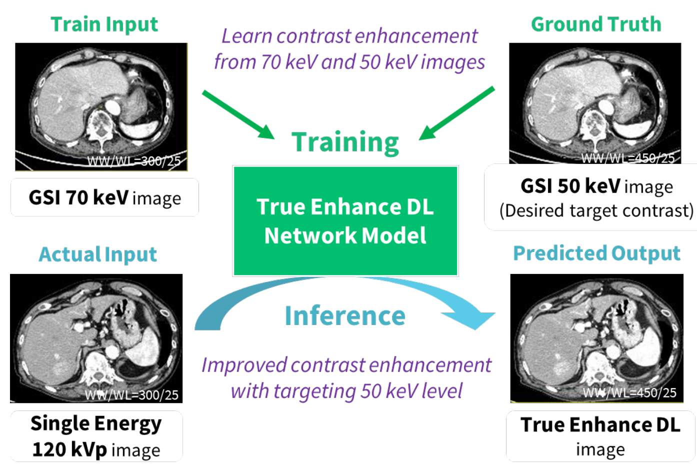


Figure 3: True Enhance DL model – Training and Inference

True Enhance DL - contrast phase-based DNN training

A key design element for proper contrast enhancement is to consider the contrast enhancement timing in the human systemic circulation system. In the typical CT contrast enhancement exam, once contrast is injected via intravenous injection, contrast travels through the body following circulation physiology. Depending on scan acquisition timing from the start of contrast injection, contrast-enhanced anatomy regions will dynamically change. Meaning the CT number of each organ will change accordingly. In a clinical situation, this circulation of contrast through the vessels and scan timing is carefully planned to capture the patient's condition in the CT images. These contrast phases are defined and can be classified into four major phases under the circulatory system-- starting with CT Angiography (CTA), then followed by Arterial, Portal/Venous, and Delayed phases. True Enhance DL offers four deep learning models the user can choose depending on different contrast enhancement phases. The four models share the same neural network but differ in the training data used for each contrast phase (CTA, Arterial, Portal/Venous, and Delayed) due to the input image CT number differences of each organ. Thus, each model is trained such that CTA brings the optimal enhancement for CTA phase scans, Arterial for Arterial phase scans, Porta Venous for Portal or Venous phase scans and Delayed for Delayed phase scans. The appropriate contrast phase selection in the True Enhance DL image reconstruction series is shown in Figure 4.

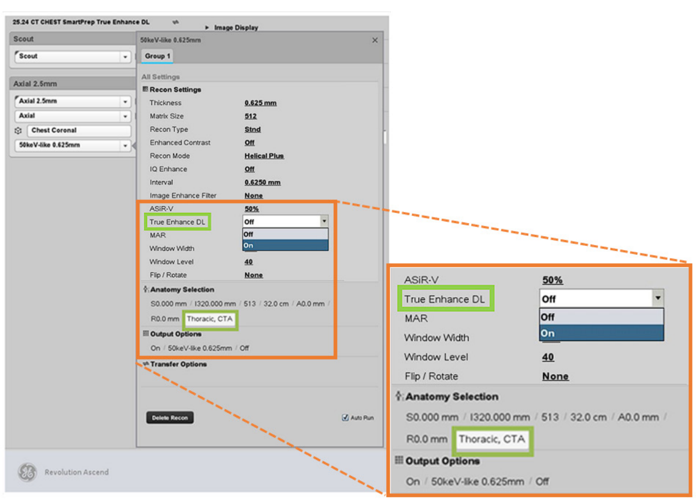
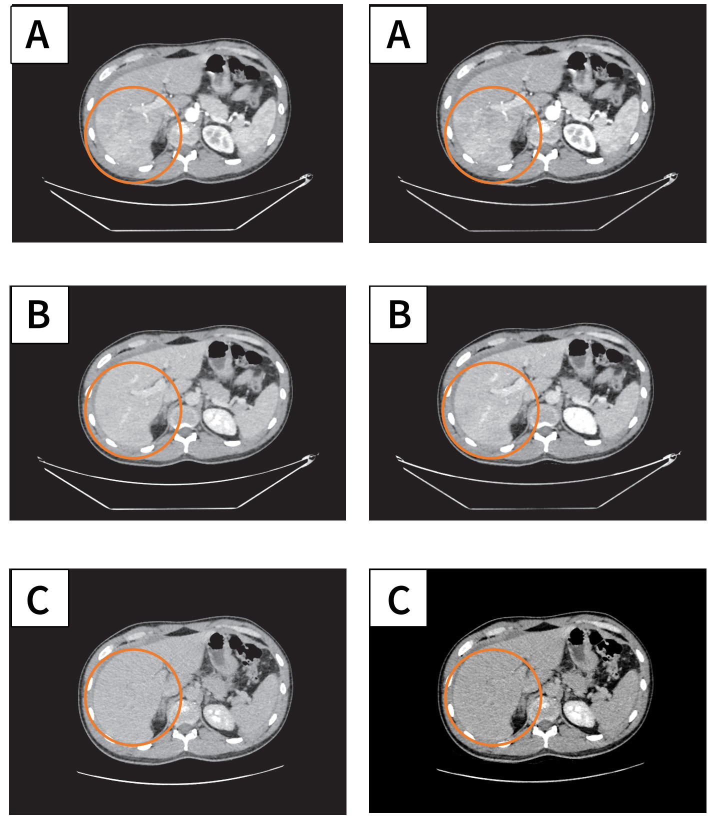


Figure 4: Neural network model selection through Clinical Identifier (CID)

Clinical examples

Case 1: Abdomen multiphase exam

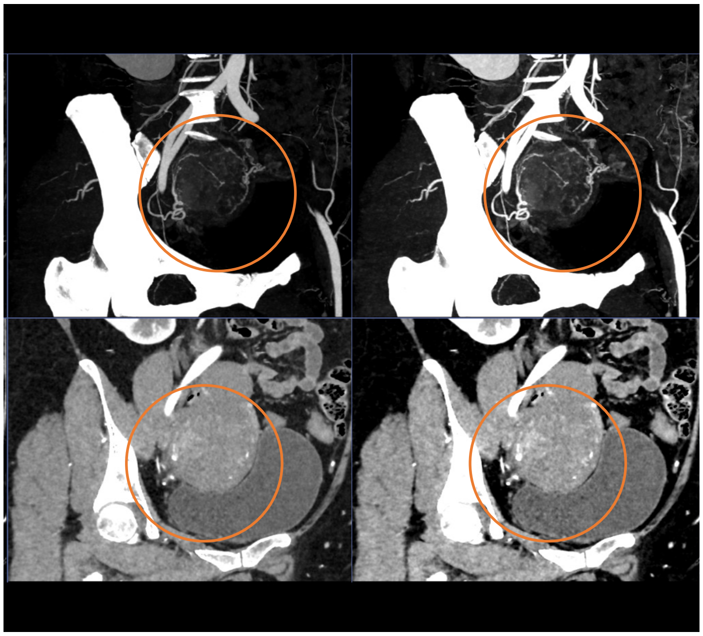


120kVp | True Enhance DL

Scan type	Helical
Gantry Rot (s)	0.5
Thickness (mm)	0.625
Reconstruction	Standard, AR80
kV	120
Noise Index	30 AR80/1.25mm
CTDIvol (mGy)	6.83
Contrast (ml/sec, ml)	2.5ml/sec 90ml

This case is a liver cancer multi-phase scan with the same exam using 120kVp and True Enhance DL. As an example, by adapting the optimal neural network to each contrast phase, True Enhance DL enhances the arterial phase where the iodine flows into the tumor, making it easier to confirm the size and extent of the tumor and peripheral vessels. In the portal phase at 120 kVp, not only are the arteries and veins enhanced, but also the liver parenchyma. True Enhance DL images show similar behavior. In the delayed phase, both 120 kVp and True Enhance DL images do not enhance the CT number in parenchyma other than in renal parenchyma, thus not interfering with understanding blood flow dynamics. (A: Arterial phase, B: Portal phase, C: Delayed phase)

Case 2: Artery enhancements exam

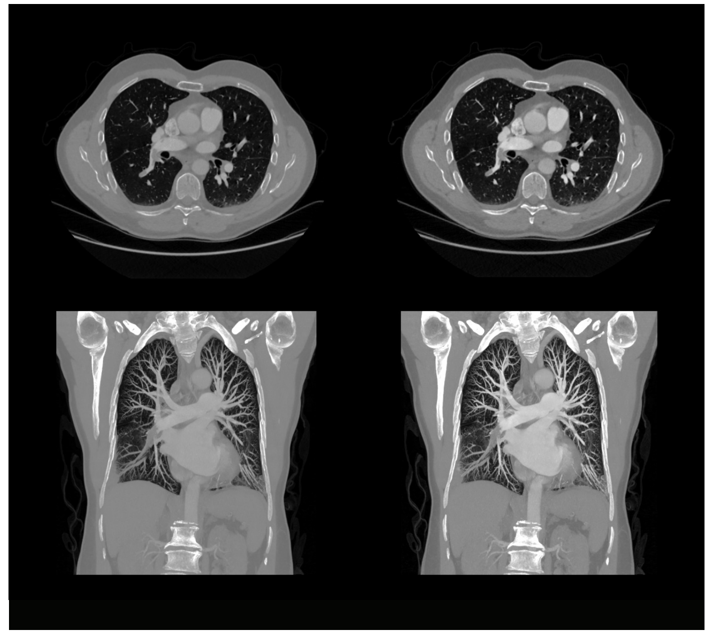


120kVp   True Enhance DL

Scan type	Helical
Gantry Rot (s)	0.6
Thickness (mm)	0.625
Reconstruction	Standard, AR70
kV	120
Noise Index	10 AR0/5mm
CTDIvol (mGy)	-
Contrast (ml/sec, ml)	-

This case is a colon cancer arterial phase case reconstructed with 120kVp and True Enhance DL (Arterial CID) images from the same exam. The images with True Enhance DL in this case show pale blood vessels flowing into the colon mass and the shape and size of the mass, making it easier to visualize the three-dimensional structure.

Case 3: Pulmonary embolism exam

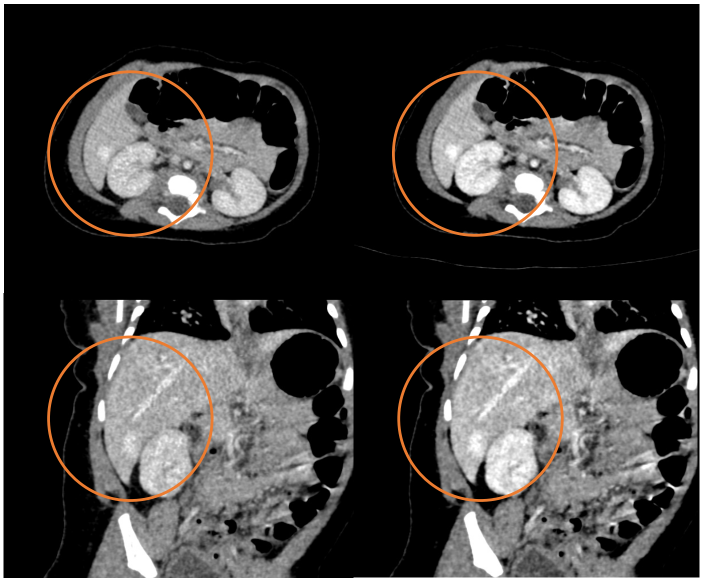


120kVp   True Enhance DL

Scan type	Helical
Gantry Rot (s)	0.35
Thickness (mm)	0.625
Reconstruction	Standard, AR60
kV	120
Noise Index	10 AR80/1.25mm
CTDIvol (mGy)	6.09
Contrast (ml/sec, ml)	4.0cc/ml 40ml

This case involves pulmonary embolism reconstructed with 120kVp and True Enhance DL (CTA CID) images from the same exam. In this particular case, True Enhance DL makes the difference in iodine CT values between the artery and vein clear and easy to distinguish, improving visibility of peripheral blood vessels and embolized regions.

Case 4: 4-month-old 3.52 kg Pediatric exam

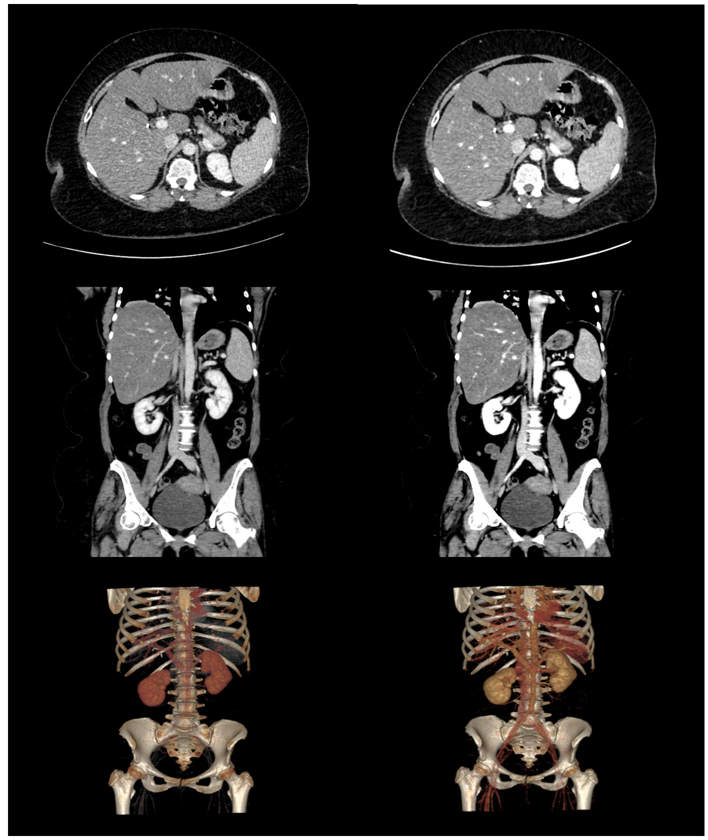


120kVp True Enhance DL

Scan type	Helical
Gantry Rot (s)	0.4
Thickness (mm)	0.625
Reconstruction	Standard, AR40
kV	120
Noise Index	18 AR0/2.5mm
CTDIvol (mGy)	1.32
Contrast (ml/sec, ml)	-

This case compares True Enhance DL (Portal/Venous CID) and 120kVp in pediatric imaging from the same exam. In this particular case, True Enhance DL provides improved visual contrast even in pediatric imaging where blood flow is rapid, allowing clear visualization of contrast enhancement in vessels and masses.

Case 5: BMI 42 large patient exam



120kVp True Enhance DL

Scan type	Helical
Gantry Rot (s)	0.8
Thickness (mm)	0.625
Reconstruction	Standard, AR50
kV	120
Noise Index	18 AR40/2.5mm
CTDIvol (mGy)	22.83
Contrast (ml/sec, ml)	-

This case demonstrates True Enhance DL Portal CID. In this particular case, the contrast is recovered even in a large patient with insufficient contrast enhancement. Iodine-based contrast-enhanced areas (abdominal aorta, veins, and intrahepatic vessels) are enhanced with True Enhance DL images.. The liver parenchyma in this case was not contrast-enhanced even at 120kVp. Similarly, in True Enhance DL, the liver parenchyma is not enhanced and the CT numbers of the spleen and kidney parenchyma increase in response to enhancement with iodine-based contrast, similar as 120kVp.

Comments from Dr Koffi, Chief Radiologist of Polyclinique Grande Synthe

"Through the external evaluation of True Enhance DL, we utilized this new technology for Aortic CT Angiography and multi-phase abdomen CT scans. The images now confirm that we are able to achieve consistent contrast resolution enhancement. We intend to continue incorporating it into our routine protocols."

Conclusion

These early studies are based on small, single-center experiences with limited patient demographics and specific disease indications with single-energy CT protocols. Because of this, the results obtained in these studies are not generalizable, may not be reproducible and ultimately require more larger scale studies.

True Enhance DL was developed by the GE HealthCare global CT Engineering and Advanced AI/Data Science team's dedicated efforts. New AI-based capabilities are now available in single energy scan procedures thanks to True Enhance DL. GE HealthCare continues to develop spectral capabilities through hardware-based high performance imaging as well as AI/DL based novel imaging solutions to meet various clinical purposes in the diverse market needs.

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