Reducing Dose and Increasing Iodine Signal: Gastrointestinal Applications for Dual Source CT

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Introduction to Dual Source CT

Dual source CT is a CT scanner geometry that uses two x-ray tubes and two detectors on a single rotating gantry. To fit within the CT gantry, the detector of the second tube is smaller than the first, corresponding to a 26 cm field of view (FOV) vs. the typical 50 cm FOV. Each tube has its own 80 kW generator and 32 x 0.6 mm detector array and can apply double z-sampling using a flying focal spot. The system is shown in Figure 1.

The dual source CT system can be operated in three distinct dual-tube modes (in addition to modes that only use one tube).

- Cardiac mode: the 2nd tube is used to improve temporal resolution
- Dual-energy mode: the 2nd tube is operated at a different tube potential (energy) and tube current
- Dual-source (obese) mode: the 2nd tube is operated at the same tube energy and current

The focus of this educational exhibit is dual source mode scanning. This mode is referred to as the "obese" mode on the user interface, since a key application is to increase the available x-ray power to improve image quality or scan time in obese patients. In our early work with this system, we have found that the mode is useful for a much broader range of clinical applications, which will be discussed here.

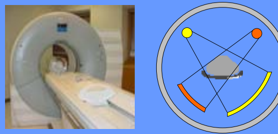


Figure 1. Dual source CT scanner geometry

Benefits of Dual-source Mode in Abdominal CT

In obese patients, deliver sufficient dose to achieve desired image quality, without increasing scan times

For morbidly obese patients, single source scanners require thicker collimation, slower tube rotation times, and/or slower table speeds in order to obtain diagnostic image quality. These parameter constraints may limit the use or quality of some clinical applications, such as multi-phase enterography. (Figure 2)

In non-obese patients, deliver sufficient dose to achieve the desired image quality at decreased scan times

Decreased scan times allow complex multi-phase examinations to be performed and are also beneficial for pediatric, non-cooperative or acute conditions.

Allow decreased kV imaging in a wider range of patient sizes

At lower tube energies, the attenuation of iodinated contrast material is increased, increasing iodine signal by up to a factor of 1.7 relative to 120 kV.

Lower tube energy imaging (e.g. 80-100 kV) has also been shown to decrease radiation dose in pediatric patients for the same or improved contrast to noise ratios (CNR).

Because intravenous iodinated contrast is widely used to accentuate disease in abdominal imaging, low kV dual-source CT scanning has the potential to increase organ and disease conspicuity (increased CNR for equivalent dose) or reduce radiation dose (for equivalent CNR) in adults due to the increased power from the 2nd source.

Current single-source CT scanners are limited in their ability to scan at lower tube energies because the tube current needed to maintain diagnostic noise levels for most adults exceeds the system limits. We have found that one of the principal advantages of dual source CT for abdominal imaging is that it extends the possibility of lower kV scanning (i.e., 80 – 100 kV) to a larger range of patients. We believe the lessons learned using today's dual-source CT scanners will be able to be directly translated to tomorrow's single source CT scanners, which will have larger generators, so that they will not be tube-current limited (at low tube energies or in morbidly obese patients).

Limitations of Single Source CT at Low kV

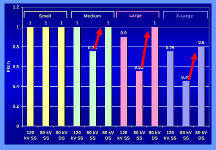
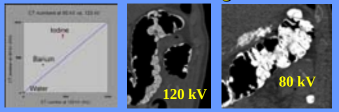


Figure 2. Dual-source kV preserves pitch at larger patient sizes.

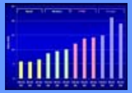
This figure shows pitch for dose-matched scanning (held constant for patients of each size; higher for larger patients) at 120 and 80 kV for patients of different sizes. When matching for dose in medium to large patients, single source CT scanners must reduce pitch to achieve appropriate noise levels at 80 kV (80 kV SS in figure). Because two x-ray tubes are employed in dual-source CT, pitch can be maintained at 80 kV for much larger patients. The red arrows indicate the increased pitch afforded by dual vs. single source CT for medium to extra large patients.

Low kV CT Acquisition: Increased Contrast vs. Reducing Dose

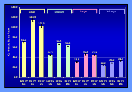


The CT number for barium and iodine is approximately 1.7 times greater at 80 kV. Because barium and iodine are used extensively in GI imaging to highlight pathology or gut lumen, low kV imaging may be used to increase conspicuity or reduce radiation dose. The above images show prone coronal images of the transverse colon in same patient at 80 kV and 120 kV (with the same window/level) during a non-cathartic CT colonography exam, with dramatic increase in colonic fold conspicuity and mean increase in tagged stool CT number (695 to 1193 HU). Due to beam-hardening effect, the iodine signal in larger patients is lower relative to that in smaller patients for a given kV.

The following figures compare noise and contrast-to-noise ratios at 120 kV and 80 kV for the same radiation dose in single-source mode (SS) and dual-source mode (DS) for anthropomorphic phantoms of different sizes.

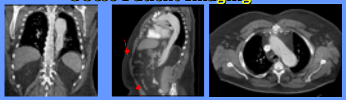


In dual-source mode, noise at 80 kV is larger than at 120 kV for all phantom sizes. For the extra-large phantom size, noise for the single-source mode is significantly higher than for the dual-source mode due to electronic noise.



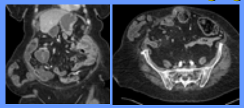
Both contrast (or signal) and noise increase during low kV CT acquisition. This figure shows contrast-to-noise ratios at 120 and 80 kV at identical dose levels. *80 kV offers dramatically increased contrast-to-noise for smaller patients, but much smaller increases for large patients.* Alternatively, for small patients, contrast-to-noise could be held constant and 80 kV tube currents could be lowered to reduce radiation dose.

Obese Patient Imaging

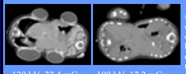


Dual source CT is utilized at high kV (both tubes at 120 kV or 140 kV) for morbidly obese patients. Using both tubes permits use of faster tube rotation times and thinner collimation and slice thickness because higher tube currents can be delivered. The use of the second tube also decreases noise without affecting signal. The above 405 pound patient with an aortic dissection was scanned with both tubes operating at 120 kV, a 450 eff mAs, pitch of 0.9, 0.5 second tube rotation time, collimation 64 x 0.6 mm, with images reconstructed to 2 mm and a total scan time of the chest and abdomen of 17 seconds. In the sagittal view, one can appreciate the decreased signal anteriorly in the subcutaneous fat (arrows), as only the output from the larger detector contributed to this portion of the image.

Decreased Scan Time Imaging



The above elderly, obese female was scanned using a dual source 120 kV technique as part of a triple-phase CT enterography exam for occult GI blood loss. As part of this protocol, the arterial and enteric phase are 20 seconds apart. Using a 240 mAs Quality ref. mAs and dual source mode, the pitch was doubled (as compared to identical parameters using only one x-ray tube) to permit scanning the abdomen and pelvis in 7.5 seconds for each phase of contrast enhancement.



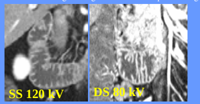
120 kV, 22.4 mGy | 100 kV, 12.2 mGy

The left image was acquired with a single source at 120 kV. The right image was acquired with a single source at 100 kV. Both cases were performed for conjoined twins (left-IV contrast; right-CT cholangiogram). Switching to 100 kV lowers the dose by about 50%. However, in order to deliver sufficient dose with 100 kV, the helical pitch had to be lowered to 0.6, prolonging scanning time. If the dual-source scanner were used, the same dose reduction could have been achieved without sacrificing scan speed, which is very important for pediatric patients.

Low kV Imaging to Increase Iodine Signal and Conspicuity

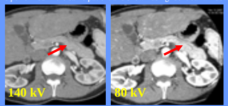
Appearance of Normal Organs

The internal architecture of most abdominal organs is appreciated using iodinated contrast. The consequent increased organ contrast at low kV settings can highlight anatomic structures, but may result in a need to use alternative window and level settings (as organs will appear too bright). Low kV scanning should be avoided in large patients because image noise will result in poorly defined boundaries. The images below illustrate changes in organ contrast. Each pair of images is performed in the same patient and shown using identical window/level settings.



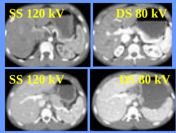
GUT

Note increased contrast between duodenal folds and neutral enteric contrast.



PANCREAS

Note dramatic signal increase in the pancreatic parenchyma at low kV, permitting better visualization of the pancreatic duct. In this example we obtained images using dual energy mode (using tube energies of 140 and 80 kV), so we could display the pancreatic duct on identical sections, showing the output of each tube at the same location in the pancreatic phase.

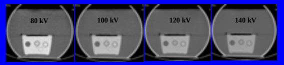


LIVER

Note increased contrast in both the portal vein and liver parenchyma in these two patients.

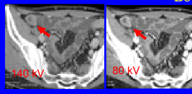
Increased Conspicuity of Disease

Increased Conspicuity at Lower kV

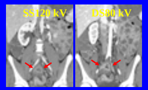


A container simulating the attenuation of enhancing liver was placed inside a water bath, along with three tubes (water, slightly lower and slightly higher attenuation). Note increased contrast of the container and non-water tubes at 80 kV. Additionally, the CT number difference between the background container and the tube with higher attenuation was maximized at 80 kV (Δ_{80} = 35 HU; Δ_{100} = 23 HU; Δ_{120} = 19 HU; Δ_{140} = 16 HU).

Bowel



Increased conpsicuity of inflammed bowel. Note the increased iodine signal in the 80 kV image, which highlights mucosal hyperenhancement in the terminal ileum (red arrows) in this 20 year-old male with active Crohn's disease.



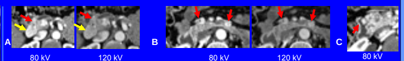
Interloop abscess. This patient had a single source 120 kV and a dual source 80 kV exam 2 weeks apart. Note the difference in the contrast in the abscess wall (red arrows).

Pancreas

To demonstrate the conspicuity of hypo- and hypervascular pancreatic neoplasms, we have utilized dual-energy pancreatic CT exams, showing the output of the high and low energy tubes.

3 weeks prior, 120 kV Hepatic phase | 140 kV tube Pancreatic phase | 80 kV tube Pancreatic phase | 140 kV Hepatic phase

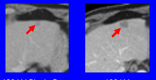
The pancreatic duct is obstructed by the tumor. CT number differences between the gland and tumor are greatest at 80 kV (172 HU compared with 95 HU at 140 kV).



80 kV | 120 kV | 80 kV | 120 kV | 80 kV

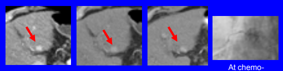
Tumor diagnosed on outside 120 kV scan as a duct-obstructing adenocarcinoma. 80 kV image clearly shows the tumor is hypervascular, along with retro-duodenal nodal mets (A). Note also how small nodal hypervascular metastases are best seen at 80 kV anterior to the duodenum (B). Finally, note synchronous tumor or invasion of duodenum (C).

Liver and Varices



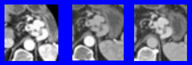
120 kV Single Source 3 months earlier | 100 kV Dual source

Colorectal metastasis is more apparent at 100 kV DS CT due to increased signal of enhancing liver parenchyma.



80 kV | 140 kV | 120 kV prior | At chemo-embolization

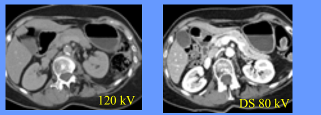
Patient with multifocal HCC.



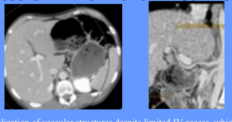
80 kV | 140 kV | 120 kV prior

Varices in patient with cirrhosis and portal hypertension.

Reduced Iodine Concentration: Poor IV Access or Mild Renal Insufficiency



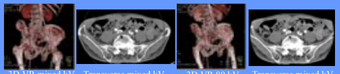
Two CT images from the same patient with poor IV access obtained only 15 days apart. Injection rate was 2 cc/s for both scans, both utilizing the same dose of iodinated contrast. Note increased iodine signal on the left due to use of low kV.



Good visualization of vascular structures despite limited IV access, which required **hand injection of 105cc of Omnipaque 300 over 3 minutes (=0.6cc/sec),** then scanned with dual source at 80 kV.

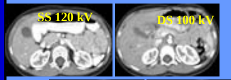
In patients with limited IV access or renal insufficiency, low kV enhances the ability to obtain excellent quality images even though administered IV contrast volumes are low or injection rates are slow.

Low kV Imaging to Decrease Radiation Dose



3D VR mixed kV | Transverse mixed kV | 3D VR 80 kV | Transverse mixed kV

The mixed kV images result from the blending of the output of two tubes from a dual-energy CTA exam. Our dual-energy CTA exam saves 20 – 30% dose over its single tube counterpart. Note that in smaller patients, diagnostic images are possible using the output of the 80 kV tube only, meaning that dose reductions of over 50% are possible in these patients.

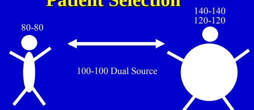


We currently utilize a dual source 100 kV exam in routine pediatric CT that saves approximately 20% dose, but uses the second tube to scan faster (by decreasing tube rotation time down to 0.33 sec and preserving pitch).

80 kV routine reconstruction | 80 kV with denoising | Mixed image (twice the dose)

Potential for radiation dose reduction with 80 kV scanning and denoising. Contrast-enhanced images obtained from a dual-energy CT enterography exam. Left-most image shows output from the 80 kV tube reconstructed using a commercial kernel. Middle image shows output from 80 kV tube after projection space denoising and image reconstruction. Note the improved visualization of the mural stratification in the neo-terminal ileum after denoising. Right-most image shows the combined output of both tubes (80 kV + 140 kV), with questionable improvement in image quality despite the fact that twice the radiation dose was required to obtain the image.

Patient Selection



While low kV scanning offers great potential for increased organ and disease conspicuity on the basis of iodine signal, it does so at the cost of increased noise. In small and medium-sized patients, only a small increase in noise results when operating both tubes at 80 kV given the larger tube current range afforded by dual-source CT. For larger patients, however, beam starvation artifacts make low kV scanning untenable. As patients get larger, alternatives for achieving diagnostic scanning include single source CT at a higher tube energy. For morbidly obese patients, single source CT requires sacrificing image quality by reducing spatial resolution and acquisition time. In such patients dual-source CT at higher tube energies permits image quality and acquisition time to be largely maintained.

Recommendations

Using our preliminary experience, we are forming guidelines as to which patient sizes should be scanned at the various dual-source energies (80/80, 100/100, etc.) These guidelines are dependent on a site's specific reconstruction parameters (slice width, reconstruction kernel, etc.) and image quality preferences. Currently we perform 80/80 kV imaging on patients with lateral widths at the level of the liver below approximately 32 cm, although the patient's specific body habitus (e.g. AP width) will also affect our choice of kV.

When implementing dual-source, low kV imaging, site's should begin with relatively thin adults to determine at what size patient they find the 80/80 kV image noise unacceptable, in spite of the increased contrast. As patients become larger, 100/100 kV scanning should be performed. This strategy can be extended up to morbidly obese patients where the use of 140/140 kV scanning may be most appropriate.

Conclusions

- Dual source CT using low kV scanning can permit marked increases in disease conspicuity, if the patient is of appropriate size.
- Dual source CT facilitates faster scanning when scanning morbidly obese and pediatric patients.
- Radiation dose reduction can be achieved using dual source low kV scanning when contrast to noise is held constant.
- Ongoing work includes methods for selecting optimized dual source tube energies based on patient size and type of exam.
- Further reductions in radiation dose are possible using low kV scanning.

Disclosure

Drs. Fletcher, McCollough, Primak and Mr. Breusewitz receive grant support from Siemens Medical Solutions, which manufactures the commercially available dual-source CT scanner discussed in this work. No patients were re-scanned for the purpose of this presentation. Scans at alternative kV settings were acquired as part of routine clinical care.

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