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July 2005





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COVER: 3D rendering of the heart, aortic arch and pulmonary trunk.

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Dation's Low Dose Vision



Subtle tissue differentiation is making CT a more valuable diagnostic tool.

AUTHOR

Richard Mather, PhD Senior Manager, CT Clinical Science Toshiba America Medical Systems, Inc. ABSTRACT: CT is a versatile and valuable imaging modality in the medical industry. A CT's image quality determines its ability to aid in the care and management of the patient. Image quality has a direct dependence on the signal to noise ratio within the image and therefore has a dependence on patient dose. To enhance image quality without increasing patient dose, Toshiba has designed its Aquilion[™] 64 CFX CT scanner to be highly dose efficient and use innovative software algorithms to allow superior image quality with low dose scanning techniques.

Introduction

The sole purpose of a CT scanner system is to produce diagnostic images and thereby aid a physician in the care and management of the patient. To accomplish this, the CT system must have, above all, superior image quality.

There are many parameters that describe the quality of a CT image. These include low contrast detectability (LCD), spatial resolution, temporal resolution, noise, and various artifacts. In the end, it is the CT system's ability to faithfully represent the anatomy that defines its image quality.

Image Quality

Many aspects of system design, such as the gantry, x-ray tube, detectors, and data acquisition system influence the various image quality metrics. However, nearly all the parameters that describe image quality are heavily dependent upon the signal to noise ratio (SNR) of the image. In general, a better SNR results in improved image quality. Therefore, in order to improve a system's image quality, we need to improve the SNR.

By definition, there are two ways to improve a system's signal to noise ratio: either increase the signal or decrease the noise. (*Figure 1*) The conventional solution has always been to increase the signal. This is typically done by using a higher mAs setting to produce more x-rays to pass through the patient or by using a higher kVp setting to make the x-rays more penetrating and, therefore, more likely to pass through the patient and be collected at the detector. Unfortunately, improving the signal by increasing the mA or kVp also increases the radiation dose to the patient.

Radiation Dose

Exposure to high levels of radiation causes cancer. This is a fact well documented and accepted¹. What remains controversial, however, is whether low levels of ionizing radiation, such as medical x-rays, are definitively carcinogenic². Based on the assumption that there is no lower threshold for carcinogenesis, the Department of Health and Human Services added medical x-rays to its list of known carcinogens earlier this year3. The controversy arises from the lack of enough empirical evidence to support carcinogenesis at the low levels inherent in diagnostic imaging⁴.

CT has become the primary source of man-made radiation exposure, responsible for an estimated 67% of



SIGNAL TO NOISE RATIO

FIGURE 1: Signal to noise ratio can be improved either by increasing the signal with high mAs and kVp or by decreasing the noise through efficient system design and innovative software.



FIGURE 2: Low contrast detectability, noise free. As the objects get smaller and closer in density to the background, they become increasingly difficult to visualize.

the total effective dose from medical imaging exams⁵. Due largely to its diagnostic versatility, CT use has been constantly on the rise in the last 10 years^{6,7} and the number of applications for which CT is the modality of choice has exploded. While it is well recognized that the benefits of CT imaging greatly outweigh the risks, it is critical to minimize the patient dose from CT exams in order to keep the patient risk as low as reasonably achievable (ALARA)^{4,5,6}.

The ALARA principle forms the cornerstone of radiation protection⁸. This guideline embraces and defines the risk-benefit balance inherent in diagnostic imaging. The ALARA principle is at the heart of the design vision of Toshiba's Aquilion scanner. This vision maximizes image quality and minimizes patient dose through efficient system design and innovative software algorithms.

Patient Focused Imaging

Minimizing patient dose minimizes exam related patient risk^{1,9,10}. However, a fine balance must be struck between dose related risk and image quality since the diagnostic efficacy of the images will be compromised once the



FIGURE 3: Low contrast detectability with noise. The amount of image noise has a profound effect on LCD. The smaller objects with densities close to the background disappear even with a moderate amount of noise.

image quality falls below a certain level. A dose efficient system is able to optimally convert patient dose into high quality images, allowing the diagnostic efficacy to be maintained at the lowest possible level of patient risk.

Low Contrast Detectability

One simple way of measuring the dose efficiency of a CT system is to examine its low contrast detectability (LCD). LCD is the measure of how well a CT system can visualize a small object that is very similar in density to its surrounding tissue^{11,12}. Figure 2 shows a simulated CT image with objects of different sizes and densities. Naturally, as the objects become smaller and as their CT numbers get closer to the background, they become more difficult to visualize. Figure 3 shows the effect of the SNR on the system's LCD: as the image noise increases, the ability to visualize the small objects becomes compromised. Even with a relatively low level of image noise, the smaller objects and those closer to the background CT number begin to disappear completely. It is this dependence on image noise that makes LCD a good indication of the system's ability to deal with low signal (dose) situations.

LCD is reported in terms of three parameters: object size, contrast, and dose. For example, the Toshiba Aquilion's LCD of 2mm at 0.3% at 26.7 mGy means that a 2mm object that is only 0.3% different from the background (this is equal to 3 Hounsfield units) can be visualized with a dose of 26.7 mGy. It is important that the dose is included in the specification because that gives us a point of reference to compare between systems. The clinical significance of a CT system with excellent LCD is its ability to visualize soft plaque in the coronary arteries or subtle soft tissue tumors. (Figure 4)

Maximizing Signal to Noise Ratio

To ensure the best possible image quality, the SNR must be maximized by either increasing signal, with higher mAs and kVp, or decreasing noise. Since higher mAs and kVp results in higher patient dose, Toshiba designed a system that focuses on reducing the noise. Here we will focus on three ways in which this was done:

- Minimize noise in the acquisition system
- Remove noise and artifacts from the raw data
- Remove noise from the reconstructed image



FIGURE 4: 3D Volume rendered image of the left side of the heart. Vessel probe is used to segment the LAD and show the vessel in three orthogonal planes. Seen here is complex, mixed calcified and soft plaque in the proximal portion of the vessel with extensive remodeling throughout the vessel.

30,464 Elements 35,840 Elements 57,344 Elements 1 mm <u>x 12</u> 1 mm x 1

EVOLUTION OF QUANTUM DETECTORS



FIGURE 5: Progression of 0.5mm slices in Quantum detectors from Aquilion 4 to Aquilion 64 CFX.

Acquisition System

In designing a dose efficient CT scanner, the first step is to build an acquisition system of detectors and electronics that perform well under low signal conditions. To create the Aquilion CT scanner, Toshiba's engineers combined highly the efficient Quantum Detector with precise and highly shielded electronics to ensure the quietest, truest signal possible. (Figure 5) The Quantum Detectors have fast response times and high light output to ensure maximum signal in low dose acquisitions¹³. By shielding the acquisition electronics, the amount of added electronic noise is kept to a minimum. In this way, the maximum signal is preserved for the reconstruction system.

Raw Data

Even with an optimized detector and acquisition system, highly attenuating anatomy such as the shoulders and the pelvis severely reduce the number of photons reaching the detectors in these areas. This localized reduction in photon count leads to a degradation in image quality from excess noise and streak artifacts. Conventionally,

these highly attenuating areas are imaged using increased mAs and kVp to overcome the low photon count. However, since increasing the imaging technique results in high patient dose, Toshiba engineers developed an adaptive three dimensional filter that preferentially corrects the raw data in areas with low photon count. This algorithm, known as Boost^{3D}, seeks out portions of the raw, projection data where there is a disproportionate loss in x-ray signal and applies the three dimensional filter locally to reduce the image noise and streak artifacts.

In areas of normal signal, no correction is applied and the native image quality is preserved. Such local, or adaptive, techniques produce the optimum results because the filter is applied only where it is needed. Since this algorithm removes streak artifacts caused by photon starvation, it can either be applied to enhance images using conventional mAs settings, or to allow low dose imaging with acceptable image quality by reducing the scan technique and, thereby, the patient dose. Figure 6 shows the image quality that can be achieved using this algorithm. Figure 6a



FIGURE 6: Images of a 300 lb patient with 0.5 mm slices, 120 kV, 140 mAs without (a) and with (b) the Boost 20 algorithm.



FIGURE 7: Effect of QDS. Noise levels with (a) standard technique, (b) low dose technique, and (c) low dose technique with QDS.

demonstrates cardiac and abdominal images of a large patient using a relatively low scan technique. The images exhibit typical structured noise and streak artifacts resulting from the low photon count. However, when the Boost^{3D} algorithm is applied, *Figure 6b* shows the resulting image quality: the image noise is greatly reduced and the streak artifacts disappear. By reducing the noise and mitigating the effects of low dose scanning, adaptive techniques such as Boost^{3D} are an invaluable asset in Toshiba's commitment to patient focused imaging.

Image Data

Once the detectors and acquisition systems have been optimized and the streaks and excess noise have been removed from localized areas of high attenuation, we must turn our attention to minimizing the general noise that is left in the reconstructed image. To tackle this problem, Toshiba engineers developed a unique algorithm called Quantum Denoising Software (QDS). QDS is an adaptive noise reduction filter that works on reconstructed image data by preferentially smoothing areas of uniform density while preserving the edge information of the image¹⁴. The algorithm uses locally sampled edge information within the image to blend together variable strength smoothing and sharpening filters. In areas of uniform density with few edges, the algorithm smoothes and reduces the noise. Near tissue boundaries and other complex structures where there are many edges, the algorithm blends in more of the sharpening filter to enhance the image.

QDS works in both two and three dimensions and can drastically reduce image noise allowing a corresponding savings in patient dose. *Figure* 7 illustrates the substantial dose savings possible using QDS. *Figure* 7*a* shows the relative noise in the liver of a patient using a standard scan technique. *7b* demonstrates the increase in image noise as the mAs is dropped by 47%. Finally, 7*c* highlights the ability of the QDS to reduce the noise in the liver to below that of the original, higher dose image.

Techniques of this sort are most useful in reducing patient dose when they are integrated into the scanner's automatic exposure control mechanism. Toshiba's ^{SURE}Exposure software adjusts the mAs technique



FIGURE 8a: Sagittal image shows fine detail with isotropic resolution in Circle of Willis CTA in this AVM case.



FIGURE 8b: 3D volume rendered and orthogonal views of renal CT angiogram.



FIGURE 8c: Images demonstrate the fine detail of RCA stent with clear evidence of in-stent restenosis and soft plaque.



FIGURE 8d: Curved planar image of the LAD highlights importance of low contrast detectability in the imaging of subtle soft and mixed plaques.

based on the expected noise reduction from the adaptive filter. In this way, patient dose reduction is built right into the Aquilion's console software.

Results From an Optimal System

Figure 8 shows the image quality that is achievable from a well designed system. *8a* is an excellent example of the fine detail that is achievable in arbitrary imaging planes with 0.35 mm isotropic resolution in this Brain AVM case. *8b* illustrates the routine high quality volume imaging in this renal angiogram. Thin, 0.5 mm slices allow the anatomy to be viewed in a volume rendered format with the arteries visualized in three orthogonal views. Finally, *8c* and *8d* demonstrate the need for good low contrast detectability, fast temporal resolution, and fine spatial resolution required to visualize in-stent restenosis in 8c, and soft plaque in 8d, when imaging the coronary arteries. Thin, 0.5 mm slices and advanced software algorithms such as Boost^{3D} facilitate the clear visualization inside the RCA stent with no blooming artifact. The fine, isotropic resolution and superior low contrast detectability allow the excellent delineation of the soft plaque restenosis beginning to form inside the stent. This same combination of thin slices, isotropic resolution, and LCD allows the clear visualization of subtle soft plaques and mixed hard and soft plaques with minimal calcium blooming. This sort of high quality imaging with low x-ray doses is only possible with a well designed, dose efficient system.

Conclusion

CT is a versatile and valuable imaging modality in the medical industry. Consequently, its use has exponentially increased since its inception. However, since there is a quantifiable risk associated with the radiation dose imparted by a CT scan, it is critical to keep patient dose as low as reasonably achievable while maintaining the image quality that is essential to the utility of the device.

In our commitment to patient focused imaging, Toshiba has developed the Aquilion 64 CFX from the ground up to be a comprehensive multislice CT imaging device. Through highly efficient system design and innovative reconstruction software, the Aquilion is the ideal low dose CT scanner. The Aquilion's industry leading slice thickness and low contrast resolution give it superior image quality with exceptional dose efficiency. **CA**

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Aquilion 64 Case Study

Chest Pain Triage

PROFILE: ECG gated chest study performed in 18 seconds, is the ideal examination for the triage of the patient that presents with chest pain. The 0.5mm x 64 volumetric data set can be used to evaluate the aorta for dissection, the coronary arteries for stenosis and/or soft plaque or the pulmonary tree for pulmonary embolus. The lungs can also be evaluated for interstitial lung disease or nodules.

SCAN PARAMETERS: 120kV, 0.4 second rotation, pitch 0.25, 360mA, 0.5mm x 64





Image 1: Coronal MIP of the lungs.

Image 2: 3D volume rendering of heart, aortic arch and pulmonary trunk.



Image 3: 3D volume rendered views of the heart and main coronary artery vessels, the left anterior descending artery coming off the left main and its first diagonal branch can clearly be seen, as well as the circumflex.



Image 4: Curved planar image of the left main, LAD and RCA helps in evaluating the patency of the vessel, visualization of soft plaque and vessel wall remodeling.



Image 5: CPR image of the ascending and descending aorta helps rule out aortic dissection or aneurysm.

Experience: A Dedicated Cardiovascular CT Center

On November 1st 2004, Manhattan Diagnostic Radiology opened MDR-Cardiovascular Center (MDR-CC), dedicated to cardiovascular CT and MRI. For the first five months, 800 CT angiograms were performed using a Siemens 16 detector system. In mid-March, MDR-CC installed a Toshiba Aquilion[™] 64 CFX; the first 64 detector CT system in Manhattan. Since then we have performed approximately 400 coronary CTAs. This article offers a few useful tips based upon our experience in moving from a 16 to a 64 detector CT in a busy outpatient imaging center.

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Setting It Up

A cardiovascular CT practice requires more infrastructure and personnel than a general imaging center. MDR-CC has assembled a cardiovascular team that includes a nurse experienced in administering blockers and monitoring cardiac patients, two highly trained technologists who run the CT scanner and 3D post processing lab, as well as dedicated cardiac radiologist.

Installation of a 64 detector CT system has also necessitated upgrading our network in order to process, manipulate, and store the thousands of images produced in each examination. The upgrade has included a T1 internet line, cardiac PACS, dedicated advanced image visualization workstations, and a system with web browser capability to allow referring physicians to directly view images.

Optimizing the Cardiac CTA Examination

Three factors in the image acquisition phase of a coronary CT angiogram have the greatest impact on image quality:

1- In patient preparation for the coronary CTA, vigorous beta blocking is used to slow and steady the heart rate giving us the best chance of achieving a study with



3D volume rendered reconstructions at 70% of R-R interval, Study acquired in 10 seconds using 120 KV 440 mA. FIGURE 1a: 3D VR image of LAD. FIGURE 1b: 3D VR image of RCA.

the least amount of motion artifact. In our practice, patients receive oral beta blockers the night before and the morning of the study, and IV beta blockers during the examination.2- During the examination optimization of contrast timing is important in order to produce a tight contrast bolus in the coronary arteries, for the greatest opacification of the coronary arteries, and the best contrast to noise ratio

between the open vessel lumen and soft plaque. Contrast should be bright in the left ventricle and hardly visible in the right ventricle (*Figure 2*);

3- After the examination, images of the coronary arteries need to be reconstructed at the phase in the cardiac cycle (different points in the R-R interval) during which there is the least amount of coronary motion. This requires the technologist (and or physician) to examine the images and, if necessary, produce additional datasets at different percents of the R-R interval (*Figure 3*). Sometimes the right and left coronary arteries are best seen at different times within the R-R interval. If the patient has multiple premature ventricular contractions (PVCs), ECG editing can be performed to remove images acquired during these PVCs from the reconstructed images (*Figure 4*).

Even with the best efforts on any scanner, the patient may move or the heart rate may vary greatly during the exam, causing significant motion artifact. It's important for the technologist to examine the images before the



^{sune}Start facilitates good contrast timing which is essential for getting good Coronary Artery CTAs. FIGURE 2a: Axial image demonstrating poor contrast timing with CM concentration greater on the right side of the heart than the left. FIGURE 2b: Axial image demonstrating perfect contrast bolus timing. Notice the high conspicuity of the RCA when the correct contrast timing is used (red arrow).



FIGURE 3a: Axial image of coronary CTA reconstructed at 70% of the R-R interval.

FIGURE 3b: The same axial slice reconstructed at 541 ms. Notice the decreased blurring in the image when the advanced editor is used.



FIGURE 4a: Axial slice in a patient who had multiple PVCs during the examination resulting in blurring of the RCA (red arrow).

FIGURE 4b: Same slice with the images acquired during the examination where the Premature Ventricular Contractions (PVCs) have been removed.



FIGURE 5a: Curved reformat through the LAD. The red arrow depicts an eccentric soft plaque in the vessel.

FIGURE 5b: A cross sectional view at the level of the soft plaque in the LAD. The yellow arrow points to the outer wall of the vessel demarked by the soft plaque. The soft plaque has expanded the vessel wall: an example of positive remodeling.

patient gets off the table to determine if the exam was adequate. If not adequate, the physician monitoring the examination must be alerted and decide whether to repeat the study or to let the patient go, keeping in mind the additional radiation and contrast that this will give to the patient. The number of inadequate cases can be minimized by paying attention to optimization of the patient's heart rate, timing of the contrast bolus and reconstructing the images at the optimal R-R interval. Our goal is to not have to recall any patients for additional images. Our recall rate is under 2%.

Image Interpretation

A poor image is likely to produce a less accurate reading, no matter how expert the reader. Image quality is the most important factor affecting image interpretation because vessels of varying sizes must be visualized from multiple angles. Also of key importance is the need for experience in interpretation of coronary CTA exams. In cases with complex plaque, the lesion must be viewed in several orthogonal planes. At MDR-CC we have found the "on face" view of the vessel (perpendicular to the long axis) to be the most useful in quantifying the percent of stenosis. This is especially true in the coronary arteries where positive remodeling occurs. In positive remodeling, the vessel wall can expand 50% or more before causing narrowing of the vessel lumen. (Figure 5) The "on face" view of a vessel, being an oblique reformat, will be distorted the further the image acquisition is from isotropic.

Workflow

Cardiac datasets can get extremely large due to the need to reconstruct multiple phases. Therefore, as the number of cardiac cases performed per day increases, the need for efficient workflow becomes increasingly important. MDR-CC has developed a 3D lab to improve case throughput. We have found the Vital Images workstation to be very user friendly, allowing the physician and technologist to quickly post process images. A unique feature of this workstation is the ability to easily export images into reports.

Reporting

Our cardiac CT reports include a coronary calcium score, a vessel by vessel analysis of soft plaque and percentage of stenosis, evaluation of the visualized lung fields, and a recommendation based upon all the findings. Currently, there is no similar formal recommended reporting system for mammography used by BIRADS. In our practice, we divide patient findings into four categories to help with therapeutic decision making:

1- For mild atherosclerotic disease, no obstructive stenosis or significant non-calcified plaque, continued medical management is recommended;

2- For significant non-calcified plaque and no obstructive stenosis, aggressive medical management and follow-up is recommended;

3- For borderline obstructive lesion (50-70% stenosis), correlation with stress test is recommended;

4- For high-grade stenosis (>70%) suspected, further







FIGURE 6a: Minimal wall thickening in the RCA.

FIGURE 6b: Focal soft plaque causing less than 50% narrowing. Aggressive medical management and follow-up were recommended.

evaluation with a stress test or x-ray angiogram is recommended. (*Figure 6*)

In our practice, the 3D lab produces a standard set of images displaying the RCA, LAD and circumflex arteries that are placed at the end of the report.

The Virtual Reading Room

Cardiac CT poses this challenge: What images should be sent to referring physicians? The most common practice is to send a CD with the axial images. Yet, this is not sufficient since, as we have said, interpretation of complex plaque in a curving vessel requires seeing the vessel in multiple orthogonal planes. We have recently installed a



FIGURE 6c: A 50-60% stenosis. Correlation with thallium stress test was recommended.

FIGURE 6d: Complex mixed soft and calcified plaque causing a high grade stenosis.

Vital Connect thin client server (Vital Images) that allows referring physicians to remotely access and manipulate images of patient examinations over the internet. The Vital Connect server also has built-in videoconferencing capabilities. Videoconferencing and remote access capabilities are very important in increasing collaboration between cardiology and radiology, and offer the potential to create a "virtual reading room."

Impact of the Toshiba Aquilion 64 CFX on Coronary CTA in our Clinical Practice

Dealing with artifacts is the greatest challenge for coronary CTA. The most common and difficult artifacts

to deal with are:

1- Motion artifact;

2- Blooming artifact from dense calcifications;

3- Inconspicuous vessel and plaque borders especially on the "on face" or cross-sectional view. The greatest impact of our 64 detector CT has been decreasing image artifact, resulting in an increased confidence in image interpretation. (*Figure 7*)

Motion artifact can be caused by imaging at an elevated heart rate, imaging during a change in the patients heart rate, imaging an irregular heart rate, or reconstructing the images at an R-R interval where the coronary arteries are moving. Using the 16 detector scanner, we found that motion accompanied heart rates above 60 bpm. With

the 64 detector scanner, we have obtained good studies in patients with heart rates in the 80s. This is due to the shorter breath hold times (5-10 seconds) required of the Toshiba 64 detector CT scanner, as well as the utilization of the adaptive multi-segment ^{SURE}Cardio algorithm. The most problematic studies are in patients whose heart rate changes drastically during scanning. This can even occur in the short 5-10 second breath hold.

Blooming artifact occurs in densely calcified plaque, which can cause overestimation of stenosis and limits our ability to evaluate patients with more advanced, longer standing disease. With our 16 detector system, we were unable to give a complete reading on all coronary segments in patients with calcium scores greater than 400. (*Figure 8*) With the 64 detector system, we have found a decrease in blooming artifact from calcified plaque. The calcified plaque can often be seen as peripheral and the



FIGURES 7a and b: 3D volume rendered views of the same patient with a heart rate of 77 bpm scanned on the (a) 16 and (b) 64 detector systems. Notice the detail of the stents in (b) where all the major vessels are stented. Notice the runoff of the Dx, LAD, and OM (red arrows) which can only be visualized on the 64 detector CT system.

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vessel lumen can still be evaluated. We have been able to evaluate several patients with a calcium score over 2000. (*Figure 9*) We believe the improved evaluation of patients with calcified plaque on our Toshiba 64 detector CT is due to thinner detector collimation (0.5mm) causing less partial volume artifact as well as faster scan times (10 seconds on average) which decreases motion and blurring. Additionally we have found that, compared to the 16 detector CT, we can trace longer segments of the coronary tree using the 64 detector CT system.

Greatest Clinical Utility of Cardiac CT in an outpatient community practice

Working together, radiologists and cardiologists are

CTA is useful

for risk stratification

of asymptomatic

patients at high risk

for CAD

exploring the role of coronary 64 detector CTA. In our practice we have found the following clinical indications to be very useful for coronary CTA:

1- Evaluation of symptomatic patients who have previously undergone coronary artery bypass surgery.
With the 16 detector CT system, evaluation of CABG took between 30-35 seconds while the 64 detector CT system takes approximately 16 seconds. With the 64 detector

CT system, we not only obtain beautiful images of both internal mammary and saphenous venous bypass grafts, but by decreasing the length of the scan we also obtain images good enough to evaluate the native coronary vasculature, which is important in therapeutic decision making. (*Figure 11*)

2- Increasingly our referring physicians are using coronary CTA as the arbiter in cases where the results of a stress thallium test do not correlate with the clinical findings. (*Figure 12*)

3- CTA is also very useful for risk stratification of asymptomatic patients at high risk for CAD. By directly visualizing non-calcified plaque, we can identify patients who do not have an obstructive stenosis but who may need more aggressive medical management and follow up. (*Figure 13*)

4- The high negative predictive value of coronary CTA is useful in patients with atypical chest pain.

5- Coronary CTA has proven to be very useful in identifying patients with anomalous coronary arteries and myocardial bridging. (*Figures 14, 15*)





FIGURES 8a and b: The same patient imaged on a 16 detector CT system. Imaging of the coronary arteries and thoracic aorta (for small ascending aortic aneurysm) required two injections on the 16 slice detector system. A major advantage of the 64 detector configuration is that we now perform this in one 18 second examination.





FIGURES 8c and d: The same patient imaged on a 64 detector CT system. Notice we are able to image from the aorta through the heart in 15 seconds with only a single injection.



FIGURE 9a: The calcium score of the patient in figure 8 was 550. On the CT detector study an obstructive stenosis in the LAD could not be ruled out due to the dense calcifications.



FIGURE 9b: Follow-up study performed on the 64 detector CT system. The LAD is confirmed of having an obstructive (>70%) stenosis.



FIGURE 9c: Curved planar reconstruction of the LAD of a 64-year-old male with a calcium score of 2363. The 64 detector CT image clearly shows less blooming artifact making it possible to confirm a diagnosis.





FIGURES 10a and b: Curved planar reconstructed images show increased length of the RCA and LAD as traced using the 64 detector CT system.





Coronary artery bypass grafts and native vessels.

FIGURE 11a: 3D Volume rendered images show two saphenous venous bypass grafts.

FIGURE 11b: Axial oblique view of soft plaque in the LAD (red arrow) and second diagonal of the LAD (green arrow) which were subsequently stented.



FIGURE 13: 39-year-old-male with a calcium score of 0 but the coronary artery CT scan shows a significant soft plaque in the LAD. This changes treatment and aggressive medical management was recommended. Soft plaque is well demonstrated on the axial and curved planar image.



FIGURE 12: Patient with a normal stress test, showing high grade stenosis of the left main, LAD and RCA as seen in these curved planar views is likely causing balanced ischemia.



FIGURE 14: Anomalous coronary artery discovered incidentally. The 64 detector configuration is a very good tool for evaluation of the anatomy and pre-surgery planning.

Radiation – How Much is Not Too Much?

This is a very sensitive issue and a scientifically difficult question to answer. There needs to be a standard for measuring radiation dose per scan. While it is very difficult to determine what radiation dose is too high for a coronary CTA exam, it seems prudent to compare CT coronary angiography with X-ray coronary angiography. While increasing the mAs may improve image quality, we must consider whether there should be a limit to the total radiation dose per patient. There are several strategies to lower the radiation dose:

1- ECG modulation can be used to employ a lower radiation dose during the systolic phase of the cardiac cycle; though there is a limitation of heart rate for which this technique can be utilized.

2- Toshiba also offers a unique Boost^{3D} reconstruction technique which can be used for all heart rates. Boost^{3D} is especially useful in reducing noise in larger patients. In this way, image conspicuity can be increased at a lower radiation dose. (*Figure 16*)

Even with these innovative radiation reduction techniques, guidelines may also need to take into account differences in patient age and whether or not other tests such as carotid or peripheral CTA should be performed at the same time.

Coronary CT Angiography Where are we Today?

With the advent of the 64 detector CT, coronary CTA is quickly becoming a useful and important tool in the



FIGURE 15: Myocardial bridging.



FIGURE 16: With and without Boost^{3D}.

evaluation of patients with CAD. Still, as good as it is, future technical improvements are sure to make it even better. On the horizon are even higher temporal resolution and shorter scan times. Ideally, we would like to obtain all images in a single heart beat, so there would be no misregistration of images obtained at different points in the cardiac cycle. Each major manufacturer is working on the next generation scanner. Toshiba* is developing a 256 detector row scanner and early scans of human patients have shown promising results.

As the 64 detector CT has transformed coronary CT from an adjunct test to a robust clinical tool, we look forward to the next generation CT to expand the clinical role of coronary CTA by further improving the accuracy of coronary stenosis quantification, providing a quantitative measurement of soft plaque burden, and to perhaps even measure myocardial perfusion. **CA**

*In cooperation with NEDO, Japan (New Energy & Industrial Technology Development Organization)

CT Risk Minimized by Optimal System Design

ABSTRACT: Medical imaging is the primary source of man-made radiation exposure. While the benefits of CT are well recognized, a single CT scan carries a quantifiable risk of death from cancer. In this context, it is critically important to understand the factors that contribute to CT dose and the techniques used to minimize that dose. Differences in system design can lead to large variations in patient dose for a given exam. These wide variations in dose naturally correspond to similarly wide variations in the cancer mortality risk to the patient between CT systems. Therefore, knowledge of the CT dose efficiency between scanners is critical in the decision making process when selecting a 64-slice CT scanner.

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CT Radiation Dose

Medical imaging is the primary source of man-made radiation exposure to the general public¹. However, there is a wide range in the amount of radiation delivered to the patient depending on the exam and the imaging modality. For example, the effective dose from a chest CT is equivalent to approximately 500 chest x-rays or 100 mammograms².

The amount of radiation exposure from a CT exam is largely underappreciated by the radiological community and almost completely unknown by the general public³. Not only does CT represent a large fraction of the collective medical radiation exposure, but its use has been steadily on the rise since its introduction^{4,5}. In the US it has been estimated that CT now represents over two thirds of the medical dose⁶.

CT Radiation Risks

There is a finite, quantifiable risk of death from cancer from the radiation dose of a single CT scan¹. The risk of death from cancer from a single CT scan ranges from 1 in 500 to 1 in 2500 depending on the age of the patient^{7,8}. A child under the age of 15 is far more sensitive to radiation, has a longer life expectancy, and is at the greatest risk. For a child under the age of 15, the risk of death from cancer from a single CT exam is about 1 in 500⁸. For a 45 year old adult, the risk of death from cancer from a single CT exam is about 1 in 1250⁷.

These estimates are based on the most widely accepted model of risk from radiation exposure^{9,10,11}. This linear no-threshold model uses atomic bomb survivor data and extrapolates from their high doses down to the levels of diagnostic imaging. While this risks involved¹². However there is controversy surrounding the overuse of CT, particularly with respect to self-referral and screening of non-high risk individuals¹³. In any event, to keep patient risk as low as reasonably achievable, it is critically important to understand the factors that contribute to CT dose and the techniques used to minimize that dose.

Factors Affecting Dose

Factors affecting CT dose include: mAs, pitch, kVp, and the minimization of overscanning. imaging, and 12-13cm diameter change for chest imaging¹⁵.

Pitch

Pitch is the ratio of table movement to active detector element size for a single gantry rotation. Pitch is inversely related to dose¹⁶. Increasing the pitch will diminish the dose, while diminishing the pitch will increase the dose.

With single slice CT, pitch was utilized to improve coverage. However, coverage is no longer an issue with multi-slice CT (MSCT), particularly when combined with advances in



Fine detail in a carotid angiography exam.

model is conservative and not yet either proven or disproven, it is universally accepted as the most appropriate way to assess radiation risk in the absence of more definitive data. This is the model used by the FDA in quantifying risk from medical imaging exams.

These data have been widely published in the radiology and medical physics literature^{1,3,7,8,9,10,11}, but have been largely ignored by the medical community. In a recent survey, only 3% of patients and 9% of referring physicians understood there to be an increased risk of cancer mortality as a result of a single CT exam³.

It is well recognized that the benefits of CT greatly outweigh the



Excellent temporal and spatial resolution in a gated cardiac exam.

mAs

Dose is directly proportional to mAs¹⁴. The mAs for an exam should be kept as low as reasonably achievable to yield a diagnostic image.

It should be kept in mind that reduction of mAs will reduce image quality along with dose, so a careful balance is needed to ensure that the necessary diagnostic information is obtained. To maintain image quality, the mAs should be adjusted to patient size. This can easily be accomplished by utilizing multiple mAs settings which are adjusted according to patient size. As a general rule, mAs should be doubled or halved for every 8-9cm diameter change in abdominal or pelvic



Exquisite detail in a renal CTA.

tube capacity, tube cooling, and data handling available with newer scanners. Therefore, with multi-detector CT pitch may be used to modulate dose rather than coverage.

kVp

Dose is proportional to the square of kVp^{16,17}. A standard tube potential of 120 kVp is usually chosen for the optimum balance of contrast, penetration and dose. However, certain circumstances warrant changing the kVp to minimize dose or optimize image quality. Low settings of 80 or 100 kVp may be utilized for pediatric imaging to minimize dose, although this is partially offset by the increase



in mAs required to maintain image quality. High kVp settings of 135-140 can be useful to increase penetration of objects with very high attenuation such as when imaging orthopedic hardware, the shoulders, or very large patients.

Overscanning

Overscanning should be eliminated to minimize patient dose. Multiplanar examinations are no longer necessary with MSCT. The isotropic resolution achievable by MSCT means that the images may be reformatted into any plane with no loss of resolution. For example, imaging of the sinuses, orbits, temporal bones and small joints is no longer accomplished with both axial and direct coronal imaging, but solely with axial thin slice scanning and multiplanar reformations.

Multiphasic examinations should also be kept to a minimum. The lack of tube and data handling constraints on modern CT scanners has led to the over utilization of multiphasic examinations with significant increases in patient radiation exposure. The thinner slices available with multi-detector CT obviate the need for multiple images through the same anatomic region. For example, while There is a finite, quantifiable risk of... cancer from the radiation dose of a single CT Scan¹

a routine lung study may be displayed at 5-7mm image thickness, the 0.5mm acquired slices are available for review to definitively determine if a small nodule contains calcification which may not be detectable on the thicker images. This may also be apparent on the multiplanar reformations (MPRs) which are now routinely performed.

Also, the length of the anatomy examined should be kept to a minimum. There is a tendency to scan a greater length than needed since there are no system limitations on coverage. Excessive scan length results in unnecessary radiation and unnecessary risk of cancer mortality to the patient.

System Design

Multiple elements of a CT system's design will impact the scanner's dose efficiency^{18,19,20,21}. These elements include both hardware and software features.

Hardware

Radiation dose is inversely related to the efficiency of the detector¹⁷. A system's low contrast detectability (LCD) is a good indication of its overall efficiency. LCD is a measurement of how well a system can visualize small objects that are similar in density to their surrounding tissue for a given dose²². Differences in the dose required to visualize a small lesion can vary between systems by as much as 73%. *Figure 1* demonstrates the higher doses required by less efficient systems.

A major contributor to a system's dose efficiency is the detector system. *Figure 2* demonstrates the differences in detector efficiency between vendors which can vary by as much as 28%. Detector efficiency is related to the light output of the detector material. Higher light output means that smaller signals will be detectable and results in better low contrast detectability (LCD). Detectors also vary widely in residual



FIGURE 3: As the number of slices increase, radiation efficiency increases due to more effective use of the entire beam.

afterglow (up to 600-fold) and decay time (up to 300 fold)¹⁹.

Shortcomings in detector efficiency can often be overcome simply by increasing the dose for an examination. However, the use of higher doses increases the cancer mortality risk to the patient from a single CT scan.

Software

Advanced software features of a system can be used to minimize the dose of a CT scan. Conventionally, this has been accomplished by automatically modulating the mA during the exam. This can be done along the length of the patient by decreasing the mA through smaller anatomy such as the neck or less dense anatomy such as the chest. However, as detector coverage becomes larger, as with the 64-slice systems, this kind of modulation becomes less effective because such a wide swath anatomy is being scanned per rotation. Similarly, mA can be modulated within an individual rotation. For example, through the shoulders, the system needs more mA right to left than anterior to posterior²¹.

With CT coronary angiography,

A system's low contrast detectability is a good indication of its overall efficiency

dose can be modulated during each heart beat with EKG monitoring. Since we are most interested in the diastolic phase of the heart cycle where there is less cardiac motion artifact, the mA can be lowered a great deal during the systolic phase without compromising image quality. Thus, conventional mA is used during diastole to obtain high quality images while lower mA is used during systole when image quality is less important. EKG modulation can lead to dose reductions as high as 50%.

Even more advanced software features reduce the overall image noise allowing a profound reduction in the mAs and therefore the dose to the patient. Two new software techniques have recently been released to reduce the overall image noise and allow for even lower dose scanning. Boost^{3D} is a novel approach to processing the raw data to reduce the noise caused by low dose techniques. Quantum Denoising Software (QDS) is a unique approach to processing the reconstructed data further reducing noise caused by low dose techniques. These techniques have an expected dose reduction of up to 40%.

Thin Slice Dose Efficiency

The change in technology from single slice CT to MSCT increased the awareness of the inherent dose increase from thin slice scanning. With 4-slice scanners, the dose efficiency diminished with very thin slices because the penumbra - the unused portion of the x-ray beam that lands outside the active portion of the detector array - becomes a much larger fraction of the total dose profile with very thin slices, thus increasing the dose. With 8 and 16 slice systems this effect is reduced, and with 64-slice systems, it disappears completely as the entire detector array is used for the thinnest slices (Figure 3).



CT Dose Index

CT Dose Index (CTDI), the conventional method of reporting scanner dose, is not useful in comparing different CT systems. CTDI is heavily dependent on the scanner's filtration. A scanner with heavy filtration may have a low CTDI, but need high mAs for adequate image quality. Furthermore, CTDI does not account for differences in detector efficiency, low contrast detectability, and reconstruction software which can play major roles in determining the scanner's dose efficiency. For these reasons, a scanner with a low CTDI may actually require a higher patient dose for a given study.

Only when CTDI is combined with the actual scan techniques used in specific examinations does it provide useful information about the radiation dose delivered to the patient²³. It is critical to examine the actual scan techniques used on different manufacturers' systems to compare the relative patient doses for a given examination. For example, for CT carotid angiography, effective mAs vary from about 181 for one vendor to 300 for another. When Knowledge of CT dose efficiency between scanners is critical when selecting a 64-slice CT scanner

adjusted for CTDI, this represents a 29% difference in the effective patient dose between these systems.

Dose Comparison

The differences in dose efficiency between multi-detector CT scanners have been well recognized. An independent German study demonstrated that the actual patient radiation exposure with routine clinical imaging for 14 common examinations varied significantly between vendors²⁴. This data is displayed in *Figure 4* and highlights the differences in CT dose efficiency between manufacturers.

These differences in system dose

efficiency have become even more apparent with 64-slice systems. Detector efficiency, low contrast detectability, and reconstruction algorithms are put to the greatest test with 64-slice systems which are always acquiring at their thinnest slice thickness. This unmasks the underlying design differences affecting dose efficiency.

To appreciate these differences, it is important to look at how the systems are used in clinical practice. Vendor distributed show site images show dramatic differences in technique.

For body imaging, effective mA ranges from 181 to 300 are seen between vendors corresponding to effective dose differences of as much as 29%. *Figure 5a* demonstrates the differences in effective dose between two major vendors.

For CT coronary angiography, effective mA ranges from 600 to 990 are seen between vendors corresponding to effective dose differences of as much as 28%. *Figure 5b* demonstrates the differences in effective dose between two major vendors.

For body CTA, effective mA



ranges from 211 to 332 are seen between vendors corresponding to effective dose differences of as much as 22%. *Figure 5c* demonstrates the differences in effective dose between two major vendors.

Conclusion

The tremendous benefits of CT are well recognized. CT should continue

to be performed whenever there is a clinical indication, including screening for appropriate high risk individuals. However, the risks of CT are generally unrecognized. In this context, it is critically important to understand the factors that contribute to CT dose and the techniques used to minimize that dose. This includes eliminating the number of unnecessary CT scans, minimizing patient dose when performing a CT scan, and reducing overscanning with CT. These factors are particularly important in the radio-sensitive pediatric age group. Finally, radiologists should select dose efficient equipment which requires the minimum dose to yield a diagnostic examination. **CA**

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Nanaging Data Overload Volumetric CT Workflow

Multi-detector CT is the fastest growing and most exciting imaging technology to come along in many years. It has revolutionized the way CT is performed and interpreted. Amazing 3D images now regularly fill the pages of books and journals and are quite familiar to most radiologists. Over the last 3 years this technology has rapidly expanded from academic centers into community hospitals and imaging centers around the country. 16, 32 and even 64-slice scanners are being installed at an increasingly rapid pace.

AUTHOR

Scott Lipson, MD Associate Director of Imaging Long Beach Memorial Medical Center The transition from a single slice or a 4-slice scanner to a volumetric scanner with 16 or more slices is not always straightforward and can be fraught with problems. Scanning with these new volumetric scanners requires both the radiologist and technologist to accept a new paradigm in how images are acquired and reviewed. Gone is the old concept of individual slices and acquisition planes, replaced simply with the paradigm of acquiring and reviewing data as a volume.

Volumetric data sets affect not only how we review the data but the type of exams we perform with CT and how we scan the patients. The most dramatic impact is in the area of CT angiography (CTA). CTA is rapidly replacing diagnostic catheter angiography throughout the body (and perhaps soon even in the heart). The purely diagnostic catheter angiogram may soon become a rarity, gone the way of the exploratory laparotomy. The benefits of volumetric imaging are not limited to CTA however. Every facet of CT imaging can be improved dramatically. For example, for musculoskeletal imaging, volumetric data sets from a single acquisition can be reconstructed in any conventional or oblique plane with no loss of resolution. Patient positioning is no longer of major importance and the need to obtain direct coronal or sagittal scans no longer exists. For trauma patients this has been an amazing revolution. With a single data acquisition multiple different exams can be rapidly generated and interpreted.

With a volumetric data set, parameters such as image

slice thickness, viewing plane and image-rendering algorithm (MPR, MIP, volume etc.) can be determined retrospectively, often on the fly, and are essentially independent of data acquisition. The radiologist now possesses almost unlimited choices for image review. This flexibility has resulted in dramatic benefits in image quality and diagnostic information and therefore patient care, but has come with an often overlooked down side: an explosion of data can clog a hospital network, send storage costs through the roof, and bring workflow to a crawl if not managed appropriately.

Fortunately, there are many strategies that can be employed that preserve the clinical and diagnostic benefits of multi-detector CT without overburdening the PACS system or destroying physician productivity. To accomplish this, the processes the x, y and z planes. A typical single slice voxel has a dimension much longer in the z-axis than the x or yaxis. This leads to adequate resolution in the plane of acquisition (usually axial) but poor quality images for MPR and 3D reconstructions. Isotropic voxels allow for true 3D imaging. No matter how the data set is projected

> there is no significant loss in resolution. Isotropic voxels are the essential building blocks for all types of advanced 3D and multiplanar visualization.

Voxel size in the x and y dimension is dependent on the image matrix size and the field of view (FOV). All current scanners routinely use a standard 512 X 512 image matrix; therefore the only independent variable for x-y voxel size is the FOV. With a small FOV such as 25cm, the voxel size is 0.5mm. With a large FOV such as 50cm the voxel size is 1.0mm. The z-axis voxel size is determined by the slice thickness of the scan. Whenever possible slice thickness should match the voxel size in the x-y dimension as determined by the FOV (Figure 1).

16-slice scanners are capable of isotropic or near isotropic acquisitions in



achieve isotropic voxels.

Data acquisition

Multi-detector CT scanners with 16 or more slices are capable of routine acquisition of volumetric data sets in almost all patients, for all exams. Volumetric data sets are defined as data sets that have been acquired over a large amount of anatomy in a short time with isotropic (or near isotropic) voxels.

An isotropic voxel is a cube, measuring the same in

most cases, except during very long scans that are time limited by a contrast injection. This may occur in exams such as gated cardiac studies and CTA runoff exams. Scanners with 32 or more slices should be able to generate isotropic acquisitions in every case.

High-level multi-detector CT scanners have removed much of the variability and uncertainty from the process of generating CT protocols. It is no longer a concern that image resolution is sacrificed for the sake of speed or viceversa. We can have our cake and eat it too. Important factors to consider when designing CT protocols besides



FIGURE 1: Isotropic voxels at 2 different fields of view (FOV). With a large FOV

(50cm) and a 512 X 512 matrix, isotropic voxels are achieved with 1mm slice thickness. With a smaller FOV (25cm) 0.5mm slice thickness is needed to







FIGURE 2: Thin slab MIP (top) and 3D volume rendered image (bottom) of a patient with a peripheral mycotic MCA aneurysm. The data was acquired with 0.5mm slice thickness and reconstructed with no overlap. Note the excellent detail of the vessels and the smooth, sharp volume reconstructions.

acquisition slice thickness are: helical pitch, radiation dose management, contrast administration and timing, and cardiac gating. A full discussion of these parameters is beyond the scope of this article.

Data reconstruction

Volumetric image review depends on starting with high quality data sets, and that requires reconstruction of thin-section data. In general, the thinnest slice thickness possible (equal to acquisition slice thickness) should be reconstructed. These thin-section images are the building blocks used to create high quality multiplanar and volume reconstructions. Because of this, the CT community refers to these thin-slice images as "raw data". Aside from slice thickness, two other important variables to consider with image reconstruction are slice overlap and reconstruction filters.

Conventional CT wisdom dictates that to achieve high quality multiplanar and 3D reformations the images should be reconstructed with an overlap of approximately 50%. This was certainly true when non-isotropic data sets with image slice thickness between 1.25mm and 3mm were the norm. However with true isotropic sub millimeter data, image quality is so good that overlapping reconstruction is often unnecessary and will substantially increase the amount of data to process (Figure 2). Overlapping reconstructions may still be useful in certain cases when the highest quality 3D images are needed. The quality difference will vary from scanner to scanner and each site must individually weigh the quality improvement against the increased amount of data. At Long Beach Memorial, using a Toshiba Aquilion[™] Volumetric CT scanner, we almost never reconstruct overlapping data sets.

Choice of reconstruction filters is an important decision that will affect both image quality and data volume. All scanners offer a wide range of reconstruction filters ranging from smoother filters best used for soft tissue reconstruction, to sharper filters used more for bone or lung. In general, smoother (soft tissue) filters are used to reconstruct the raw data, as sharper filters will often produce images that are unacceptably grainy, particularly when looking at very thin slice sections. Smoother soft tissue reconstruction kernels also generally produce betterlooking 3D volume and surface reconstructions (*Figure 3*).

True raw data can be reconstructed with as many different filter kernels as necessary to provide the desired information. For example chest scans can be routinely reconstructed with both a soft-tissue filter as well as a sharper filter to better see lung detail. Another way to achieve a similar look and save storage space and reconstruction time is to apply an edge enhancement algorithm to the images after they are reconstructed. Most PACS systems allow for a sharpening filter to be applied to the images as a post-processing feature. This approach is not quite as good as applying the filter directly to the CT raw data, but it can be a good compromise for sites that want to decrease the number of images reviewed and stored, and speed up reconstruction times. Special scanning techniques and filters can also be applied on the scanner for orthopedic cases to reduce artifacts in patients being scanned with metal rods or joint prostheses in place.

CT manufactures can recommend certain kernels for reconstruction of images for different types of cases, but I recommend that each site work with their applications people to try out various options and choose the filters that they like best for each

different exam. Applications specialists can take the same data set and reconstruct images using different filters for direct comparison by the radiologists. The decision whether to reconstruct the data in a single (soft tissue) algorithm or multiple algorithms (soft tissue, lung, bone) must be decided by each site. The benefits of multiple reconstructions are better image quality for bone and lung studies, but the disadvantages are significant and include longer reconstruction times for each case, increased network traffic, and much more data to review and archive. Especially when much of the same benefit can be achieved using post-processing features on a PACS workstation.

Data post-processing

Post-processing of CT data is an essential part of the multi-detector CT examination and may occur directly on the scanner, on an independent workstation or even entirely on the PACS viewing station.

A fundamental benefit of volumetric data sets is the ability to quickly and easily review very high quality multiplanar images. With multi-detector CT, multiplanar

Thin-section images are building blocks for high quality multiplanar and volume reconstructions imaging should be part of the routine practice and incorporated into almost all CT exams in some form. Standard thicker section (2-3mm) coronal and sagittal images are simple to create and can be reviewed quickly and efficiently. With volumetric data, radiologists are now free to interpret images in the plane that is most appropriate. In this respect CT now has the same capability as MRI. As radiologists become more comfortable with multiplanar imaging, diagnostic

accuracy and confidence unquestionably improves. Many diagnoses are now much easier to make in non-axial planes. This can be difficult to fully understand and appreciate until it becomes a routine part of your practice.

The decision of where to create multiplanar images will vary from site to site depending on network and PACS capabilities and storage limitations (*Figure 4*). MPR images created directly on the CT scanner and sent to PACS have the advantage of being immediately and permanently available to the radiologists and clinicians. Thicker slice images in the axial, sagittal and/or coronal planes are generated for reviewing and archiving. The thin section data is then discarded from the scanner after a few days. The main advantage of this approach is speed and efficiency. Fewer images are sent through the network and archived on PACS. Very large data sets that can clog networks, slow PACS terminals and increase storage costs are avoided.

A second, different approach is to send the thin section data directly to PACS for post processing and archiving. Many PACS systems allow the user to easily create and review multiplanar images in any plane. This approach



FIGURE 3: Sagittal and 3D volume reconstructions of a patient with severe arthropathy of the ankle with large subchondral cysts. The slice thickness was 0.5mm reconstructed with no overlap. 3a and 3b are reconstructed with a soft tissue algorithm, while images 3c and 3d are reconstructed with a bone algorithm. Image quality is much better seen on the sagittal image with the bone algorithm. This image is much sharper and shows far more bone detail. The 3D reconstruction is better with the soft tissue reconstruction however. This image is smoother and less noisy.

MULTIPLANAR RECONSTRUCTION OPTIONS



FIGURE 4: Time and storage space can be saved by reconstructing multiplanar images directly on the scanner and sending only thicker slice axial and MPR images to PACS. Maximal flexibility is obtained by sending all the thin-section data to PACS and reconstructing MPR images on the workstation.

Slice thickness, image plane and rendering technique can be varied dynamically for individual cases. The downside is the amount of data that must be transferred, loaded and archived. Many networks and PACS systems are currently unable to handle this volume effectively. For these sites the first approach is recommended.

Advanced post-processing typically occurs on an independent 3D workstation or a PACS station with 3D capability. Advanced visualization techniques such as volume or surface rendering, sliding slab MIP, curved MPR, and segmentation are extremely important adjunctive techniques but are not needed in every case. They should be part of the routine evaluation of certain exams such as CT angiography and extremity CT. These images can be generated by either a trained technologist or a radiologist and sent to PACS for reviewing and archiving.

Image Review

When it comes to acquiring data, thinner is usually better, but is not always true for reviewing images. Very thin slice images are sometimes grainy with increased noise and have poorer contrast resolution than thicker images. Review of these images is slow and inefficient compared with thicker (2-5mm) reconstructions. It is a common concern among radiologists new to multi-detector CT that they will miss something important - and therefore be liable - unless they review all the thin section data in each patient. This concern is unfounded. There is virtually no significant pathology that can be identified on a 0.5mm image that would be completely overlooked on a 3mm image. Conversely, is much more likely that an important lesion could be missed on the thin sections because of poorer signal to noise (decreased contrast resolution), but seen on the thicker image. In rare instances it may be useful to review the thin section data to characterize a lesion seen on the thicker reconstructions such as a small pulmonary nodule or a subtle fracture. This is uncommon but can easily be done retrospectively when needed.

For routine cases, I recommend reviewing 2-5mm axial images and 2-3mm coronal and/or sagittal images. The slice thickness chosen should vary with the body part. 2-3mm images for exams of the brain, sinuses, neck, extremities, pancreas etc., and 3-5mm images for chest and abdomen. If the MPR images are created on the scanner, then the slice thickness will be fixed and predetermined by the protocol, and for images created on PACS or a workstation this is usually an interactive process that will vary by patient. In either case, the process should be similar. The radiologist quickly reviews a fixed, relatively small (< 300) number of images.

Cases that require advanced visualization tools such as CTA and musculoskeletal cases are often best reviewed directly on the workstation. This allows for real-time interactive review of volumes and MIPS. These cases can be effectively reviewed on PACS if a technologist has taken the appropriate images and sent them to PACS in advance.



FIGURE 5: CT workflow. Flow chart demonstrating flow of image data from the scanner to the PACS system and workstation and subsequently to the radiologist and referring doctors.



FIGURE 6: 2mm coronal reconstruction from a CT abdomen in a patient with jaundice. 2 very large stones (*) are impacted in the distal common bile duct. The coronal plane is ideal for demonstration of biliary abnormalities.

CT Workflow

There is no one roadmap for efficient CT workflow that will succeed for all sites. Each site will need a slightly different solution based on the available equipment and the preferences of the radiologists. One of the most important components to efficient workflow is setting up detailed protocols and pathways for each case (*Figure 5*). Having a detailed protocol eliminates the guesswork and minimizes errors, and saves time for both the technologist and the radiologist. If the protocol covers everything that needs to be done from start to finish, the technologist does not need to waste time figuring out what to do. The radiologist will not waste time answering unnecessary questions and when he reviews a case he can be confident that the images he expects to see will be there in the desired format.

A comprehensive protocol includes not only the parameters needed to acquire the data, but a detailed outline of how the data should be reconstructed, postprocessed and archived for each type of exam. Getting the right data to the radiologist in the proper format is half the battle.

True efficiency also requires a frame shift in the minds of interpreting radiologists. For years the CT paradigm has dictated careful review of axial images with multiplanar correlation in select cases. This paradigm is obsolete in the multidetector era with



FIGURE 7: 2mm coronal reconstruction from a CT abdomen of a patient with Crohn's disease and small bowel obstruction. A long segment of narrowed and thickened small bowels present. Note the small bowel feces sign in the dilated loop proximal to the obstruction. The pathology in this patient was much easier to characterize in the coronal plane.

volumetric data sets. Radiologists familiar with MRI can easily understand this. No experienced MRI reader would ever feel content with axial images alone. For years MRI readers have been able to review images in whichever plane best demonstrates the anatomy and pathology, and correlate the findings with other planes. CT should now be treated exactly the same way. Many, if not most exams are better suited to primary image review in the sagittal, coronal or even oblique planes. This is fairly obvious for exams like the spine, sinuses and hips, but can even be true for body cases (*Figures 6 and 7*). The body is much longer than it is wide and therefore 80 2mm coronal images can be reviewed much more quickly than 200 3mm axial images.

Making the transition from axial image based review to a true multiplanar and volumetric approach does not occur overnight. It is a gradual process that takes weeks or months to fully integrate into daily practice. The rewards are substantial as more efficient image review couples with the potential for improved diagnostic accuracy. **CA**

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Aquilion 64 Case Study

Cogans Syndrome

DESCRIPTION: Cogans Syndrome: an inflammatory disease involving the eye, ear, and aorta, characterized by uveitis, otitis and aortitis, and near total occlusion of most major vessels originating from the aorta.

PROFILE: 70-year-old female patient with known Cogans Syndrome affecting both coronary arteries, left carotid, left subclavian vessels, both renal arteries, and both mesenteric arteries. An initial coronary artery bypass graft was performed using saphenous veins, but both grafts later occluded at their ostia. A second coronary artery bypass graft was performed using bilateral mammary artery grafts. These grafts remain patent. Patient then developed angina due to progressive left subclavian stenosis, which was successfully treated by stenting.

SCAN PARAMETERS: 120 KV, 400 mA, 0.4msec, 0.25 pitch Acquired with 0.5mm x 64



Images 4 and 5: Angio-emulation rendering are used to show in these AP and AP-Oblique views which demonstrate the relationship of the vessels of the heart and the associated RIMA, LIMA and SV grafts.



Image 3: 3D Volume rendered image with the myocardial mass in background clearly show the anatomical relationship of the grafts: RIMA, LIMA and saphenous vein grafts and the inflammatory condition of the aortic root and arch and surrounding anatomy.



Image 4: Volume rendering in 3D shows the saphenous vein graft and RIMA on the right side.



Image 5: Inferior superior view from the apex shows the extent of the inflammatory condition at the root of the aortic arch extending upward and the anastamosis of the SVG and the LIMA and original LAD.



Image 6: Sagittal view of the heart and chest show the extent of the inflammation of the aortic root and aorta.

Images courtesy of Johns Hopkins Bayview, Baltimore, MD.





Heart rates are variable, image quality shouldn't be.

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