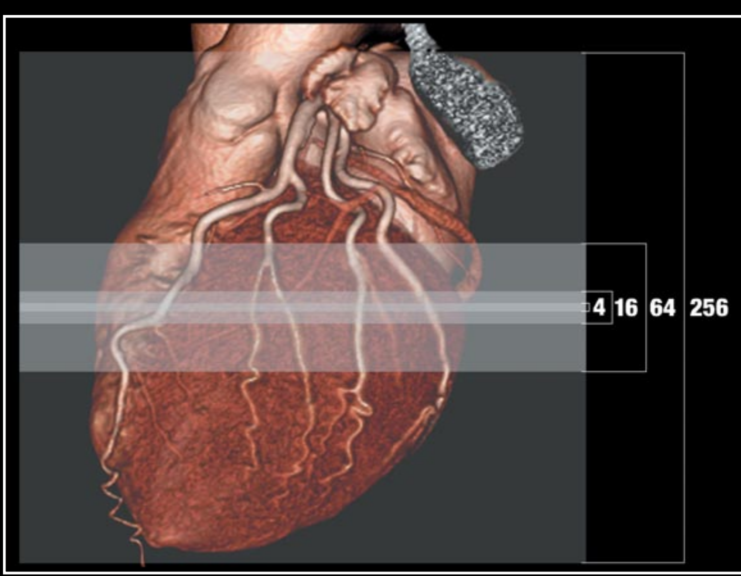
TOSHIBA

The Next Revolution: 256*-Slice CT

** Work in progress.*

Richard Mather, PhD
Senior Manager, CT Clinical Science
Toshiba America Medical Systems



From 4-16-64-slice systems, the breath-hold time for helical scanning of the heart has been significantly reduced. However, it is only with the 256-slice system that the entire heart can be covered in a single rotation.

256 Detector CT image of Human Heart with 128mm coverage per rotation.†

Made for Life

w w w . m e d i c a l . t o s h i b a . c o m

Once relegated mostly to cranial imaging, multi-slice CT has undergone a technological revitalization that's made it the modality of choice in an increasingly diverse range of clinical applications. But, as a look back reveals, the road from one slice to 256 is paved with quantum leaps in technical innovation – especially in detector design and technology.

EARLY BREAKTHROUGHS

Each technological breakthrough in CT removed old barriers and challenged the clinical community to think about CT imaging in new ways. The introduction of slip ring technology and helical scanning[1], for example, made it possible to cover volumes of anatomy within a single breath-hold, thus paving the way for lung and body imaging.

Similarly, four-slice technology enabled the first truly volumetric CT scans. Toshiba's Aquilion™ 4-detector, a hybrid detector array, created a choice between wide anatomic coverage or thin resolution slices. The Quad employs 0.5mm slice thickness to obtain isotropic resolution for images needing high resolution such as musculoskeletal imaging or Circle of Willis CTA. It can also employ thicker slices to provide large coverage in a single breath-hold when imaging the chest and abdomen. An entirely new generation of CT exams such as CT angiography, including CT pulmonary angiography, CT colonography and CT urography was made possible by this new technology. This new flood of clinical applications, however, came with the challenge of handling larger, more complex datasets which required the routine use of multiplanar and 3D images to aid diagnosis.

SIXTEEN SLICES AND SHORTER BREATH-HOLDS

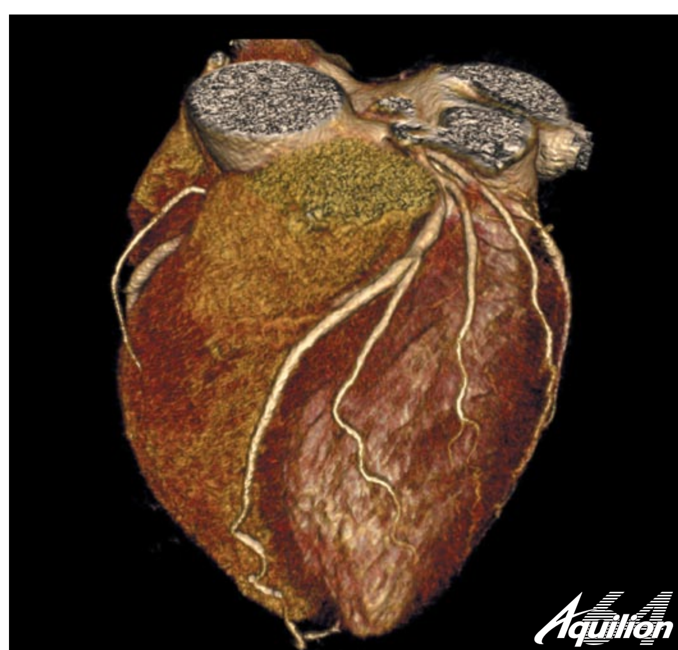
It was not until the sixteen slice systems became available that the next breakthrough in CT was realized. With the Aquilion 16 it became possible to cover the entire lung field with 0.5mm slices in about 13 seconds, which is an achievable breath-hold. It was also possible to keep up with the contrast bolus in a peripheral runoff exam. This ability to accurately image virtually any anatomy quickly made the Aquilion 16 the workhorse of many radiology departments. However, it was vascular imaging and musculoskeletal that brought Aquilion's clinical versatility to the forefront.

CARDIAC IMAGING

The Aquilion 16 produced the fine isotropic resolution necessary to depict tiny coronary vessels, while achieving a manageable breath-hold of less than 30 seconds. While there were some published papers detailing the use of four-slice coronary imaging[2,3,4,5], it was not until sixteen slice technology that widespread clinical interest took hold[6,7,8,9,10,11]. Unfortunately, with breath-hold times in the 25-30 second range, coronary imaging with the sixteen is not necessarily routine, as a percentage of the vessel segments are often non-assessable due to motion artifact because many patients were unable to tolerate the long breath-hold required.

64-SLICE ELIMINATES TRADEOFFS

Routine coronary artery imaging has only recently emerged with the advent of true 64-slice technology. Unlike any predecessors, Toshiba's Aquilion 64 covers its entire 32mm detector with 0.5mm slices, which completely eliminates any trade-off between coverage and resolution. With the Aquilion 64, clinical applications can be performed at 64 x 0.5mm slices, yielding fine isotropic resolution with excellent speed and coverage. This means that the entire coronary tree can be imaged in 6-to-9 seconds. The main advantage of these short breath-holds is that the patient's heart rate typically remains regular over this period, resulting in vastly improved coronary image quality since conventional, non-adaptive cardiac reconstruction algorithms are



most effective when the heart rate is steady. Patient tolerance of the exam is also greatly improved.

RECONSTRUCTION ALGORITHMS

For patients with erratic heart rates, ectopic beats or atrial fibrillation, a good adaptive segmented reconstruction algorithm can minimize motion artifacts and significantly reduce banding and other misregistration artifacts[12,13]. Dewey et al showed that Toshiba's SURECardio™ adaptive segmented reconstruction algorithm notably improved the sensitivity, specificity and accuracy of detecting significant stenoses and measurably reduced the number of non-assessable arteries over half-scan reconstructions of the same data[14].

WHOLE-ORGAN COVERAGE

While the 64-slice technology makes coronary artery imaging routine, its 32mm of coverage still isn't large enough to image the entire heart in a single rotation. One technology that has been proposed for true volumetric imaging is the flat panel CT system[15,16]. This system's main advantage is spatial resolution, which can be as low as 0.25mm in all dimensions. However, it is plagued by a limited field of view, slow scan speeds (which limit the temporal resolution), poor scatter rejection and poor low-contrast detectability. These limitations make the flat panel system a poor candidate for a cardiac scanner, which needs good temporal and low contrast resolution along with its spatial resolution. Dynamic cardiac imaging would not be possible with a flat panel system.

While a 128-slice system would provide 64mm of coverage in a single rotation, it still does not have enough coverage to image a 120mm heart without moving the table. This can lead to potential misregistration artifacts at the volume boundaries and, more importantly, would limit dynamic studies such as first pass perfusion. An ideal organ scanner should have the ability to image the entire organ in a single rotation of the CT gantry with no table motion.

For true volumetric cone beam CT to realize its full potential and enjoy broad clinical acceptance, it must acquire wide-area coverage while maintaining the advantages of conventional CT: fine spatial resolution, fast temporal resolution, and above all, superior low-contrast resolution. Otherwise, it becomes a niche system with limited clinical utility that can only be used for a limited number of applications.

TOSHIBA'S 256-SLICE SYSTEM

Achieving complete coverage of the heart or other organs within a single rotation requires a system capable of covering at least 120mm of anatomy with no table movement. Toward this end, Toshiba, in cooperation with the NEDO (New Energy and Industrial Technology Development Organization) in Japan, has successfully developed two prototype 256-slice CT systems[17] based on the Aquilion platform's core technology.

Utilizing Toshiba's proven gantry design and high-efficiency detector material, these systems cover 128mm of anatomy with 0.5mm slices, producing fine, isotropic resolution of the heart during a single gantry rotation.

The patented detector material featured on the prototypes offer the same excellent, low-contrast performance as the rest of the Aquilion line. Fast decay time and low afterglow properties ensure that the systems are fast enough for dynamic cardiac imaging, while excellent stopping power and high light-output make them highly dose efficient.

CLINICAL DEVELOPMENT

Over the past several years, there have been numerous reports published detailing the design, development and performance of the 256-slice scanner[18,19,20,21*]. In 2004, Mori et al compared several image quality metrics of the prototype 256-slice system with those of a conventional CT system. They found that the prototype 256 system has very similar spatial resolution, noise and uniformity between the two systems[18].

In another study, Mori et al showed that the prototype 256-slice scanner performed equally as well in standard radiographic examinations as a conventional system[22]. After scanning eight healthy volunteers on the prototype system with axial exams of the head, chest, abdomen and pelvis, they found image quality equivalent to conventional CT using the same dose.

IMAGING LARGE ORGANS

The primary benefit of wide volume coverage is the ability to perform dynamic examinations of large organs, such as the heart and liver. Funabashi et al examined Toshiba's prototype 256-slice scanner to evaluate its blood flow dynamics in porcine hearts and livers[23].

This study showed the unit's clear advantage over conventional systems in obtaining dynamic perfusion information from the entire liver. With a conventional system, it was possible to acquire phasic information of the entire volume by performing multiple helical runs or obtain dynamic information over a very limited anatomic volume, but not both. Researchers also demonstrated the Toshiba prototype's advantages in visualizing cardiac shunt flow and other blood flow disorders.

Most recently, Kondo et al used the 256-slice system to image the hearts of two human volunteers[24]. They showed that the system could successfully visualize the coronaries, myocardial contraction and myocardial enhancement during a single imaging exam. They also found the system's radiation dose to be approximately 2mSv per second, allowing either very low-dose, single-shot coronary imaging or low-dose dynamic imaging that can visualize the coronaries while concurrently obtaining detailed perfusion information. For about the same amount of radiation as today's 64-slice CT, dynamic myocardial perfusion imaging with 12cm coverage can be obtained at the same time.

CONE-ANGLE CHALLENGES

Of course, no new system is without technological challenges. One such challenge with the 256-slice prototype is related to increased cone angle. Without high-quality reconstruction algorithms, cone-beam artifacts could limit the system's diagnostic capability. Taguchi, however, showed that a modified Feldkamp-based algorithm can effectively limit artifacts due to the cone angle. He also extended the algorithm to include dynamic data produced by the system to accurately reconstruct all four informational dimensions[25,26].

REVOLUTIONIZING CT. AGAIN.

As CT scanner technology has advanced, each successive system has built upon CT's proven clinical utility with the best performance advances at 4-, 16-, and 64-slice, bringing a wealth of new clinical applications. As shown through the early research on the system, the 256-slice CT scanner provides the next quantum leap in CT technology. Finally it will be realistic to obtain whole organ evaluation and perfusion in a single rotation. This will bring about many new areas of study in functional CT imaging. Furthermore, with prospective cardiac triggering, it may be possible to acquire images of the coronary arteries with as little as 2mSv of dose. This will help make coronary CT a truly routine and mainstream exam.

Built on proven detector and gantry technology with the ability to not only perform well on conventional CT applications but also on a wealth of new applications, Toshiba's 256-slice CT system will revolutionize CT imaging, again.

References:

1. Mori I, 1986, Computerized Tomographic Aparatus Utilizing a Radiation Source, U.S. Patent No. 4,630,202.
2. Becker CR, Knez A, Ohnesorge B, Schoepf UJ, Reiser MF, 2004, Imaging of noncalcified coronary plaques using helical CT with retrospective ECG gating, Am J Roentgenol, 175(2):423- 424.
3. Achenbach S, Ulzheimer S, Baum U, Kachelriess M, Ropers D, Giesler T, Bautz W, Daniel WG, Kalender WA, Moshage W, 2000, Noninvasive Coronary Angiography by Retrospectively ECG-Gated Multislice Spiral CT. Circulation, 102(23):2823-2828.
4. Dirksen MS, Bax JJ, Blom NA, Schalij MJ, Jukema WJ, Vliegen HW, van der Wall EE, de Roos A, Lamb HJ, 2002, Detection of malignant right coronary artery anomaly by multi-slice CT coronary angiography, Eur Radiol., Dec, 12 Suppl 3:S177-80.
5. Schroeder S, Kopp AF, Baumbach A, Meisner C, Kuettner A, Georg C, Ohnesorge B, Herdeg C, Claussen CD, Karsch KR, 2001, Noninvasive detection and evaluation of atherosclerotic coronary plaques with multislice computed tomography. J Am Coll Cardiol, 37(5):1430-1435.
6. Nieman K, Cademartiri F, Lemos PA, Raaijmakers R, Pattynama PM, de Feyter PJ, 2002, Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography, Circulation 2002;106(16):2051-2054.
7. Ropers D, Baum U, Pohle K, Anders K, Ulzheimer S, Ohnesorge B, Schlundt C, Bautz W, Daniel WG, Achenbach S, 2003, Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. Circulation, 107(5):664-666.
8. Hoffmann MH, Shi H, Schmitz BL, Schmid FT, Lieberknecht M, Schulze R, Ludwig B, Kroschel U, Jahnke N, Haerer W, Brambs HJ, Aschoff AJ, 2005, Noninvasive Coronary Angiography With Multislice Computed Tomography, JAMA 293(20):2471-8.
9. Hamoir XL, Flohr T, Hamoir V, Labaki L, Tricquet JY, Duhamel A, Kirsch J, 2005, Coronary arteries: assessment of image quality and optimal reconstruction window in retrospective ECG-gated multislice CT at 375-ms gantry rotation time, Eur Radiol, 15(2):296-304.
10. Bley TA, Ghanem NA, Foell D, Uhl M, Geibel A, Bode C, Langer M, 2005, Computed tomography coronary angiography with 370-millisecond gantry rotation time: evaluation of the best image reconstruction interval, J Comput Assist Tomogr.;29(1):1-5.
11. Lawler LP, Pannu HK, Fishman EK, 2005, MDCT evaluation of the coronary arteries, 2004: how we do it--data acquisition, postprocessing, display, and interpretation, AJR Am J Roentgenol., 184(5):1402-12.
12. Hein I, Taguchi K, Silver MD, Kazama M, Mori I, 2003, Feldkamp-based cone-beam reconstruction for gantry-tilted helical multislice CT, Med. Phys. 30(12), 3233-42.
13. Mather R, 2005, Meeting the Cone Beam Challenge Aquilion's SURECardio™ and TCOT, Clinical Advancements in Volumetric CT, a Diagnostic Imaging supplement, October, 16-21.
14. Dewey M, Laule M, Krug L, Schnapauff D, Rogalla P, Rutsch W, Hamm B, Lembcke A, 2004, Multisegment and Halfscan Reconstruction of 16-Slice Computed Tomography for Detection of Coronary Artery Stenoses, Invest Radiol, 39(4): 223-229.
15. Nikolaou K, Flohr T, Stierstorfer K, Becker CR, Reiser MF, 2005, Flat panel computed tomography of human ex vivo heart and bone specimens: initial experience, Eur. Radiol., 15(2):329-33.
16. Mahnken AH, Seyfarth T, Flohr T, Herzog C, Stahl J, Stanzel S, Kuettner A, Wildberger JE, Gunther RW, 2005, Flat-panel detector computed tomography for the assessment of coronary artery stents: phantom study in comparison with 16-slice spiral computed tomography, Invest Radiol, 40(1):8-13.
17. Katada K, 2004, Current status and future prospects of MDCT. Proceedings of the Third International MDCT Sympposium, 2-6.
18. Mori S, Endo M, Tsunoo T, Kandatsu S, Tanada S, Aradate H, Saito Y, Miyazaki H, Satoh K, Matsushita S, Kusakabe M, 2004, Physical performance evaluation of a 256-slice CT-scanner for four-dimensional imaging, Med. Phys, 31(6):1348-56.
19. Saito Y, Aradate H, Igarashi K, Ide H, 2001, Large area 2-dimensional detector for real-time 3-dimensional CT (4D CT), Proc SPIE, 4320:775-782.
20. Endo M, Mori S, Tsunoo T, et al, 2003, Development and performance evaluation of the first model of 4DCTscanner, IEEE Trans Nucl Sci, 50:1667-1671.
21. Mori S, Obata T, Kishimoto R, Kato H, Murase K, Fujiwara H, Kandatsu S, Tanada S, Tsujii H, Endo M, 2005, Clinical Potentials for Dynamic Contrast-Enhanced Hepatic Volumetric Cine Imaging with the Prototype 256-MDCT Scanner, Am J Roentgenol, 185(1):253-256.
22. Mori S, Endo M, Obata T, Murase K, Fujiwara H, Susumu K, Tanada S, 2005, Clinical Potentials of the Prototype 256-Detector Row CT-Scanner, Acad Radiol, 12(2):148-154.
23. Funabashi N, Yoshida K, Tadokoro H, Nakagawa K, Komiyama N, Odaka K, Tsunoo T, Mori S, Tanada S, Endo M, Komuro I, 2005 Cardiovascular Circulation and Hepatic Perfusion of Pigs in 4-Dimensional Films Evaluated by 256-Slice Cone-Beam Computed Tomography, Circ J, 69(5):585-589.
24. Kondo C, Mori S, Endo M, Kusakabe K, Suzuki N, Hattori A, Kusakabe M, 2005, Real-Time Volumetric Imaging Of Human Heart Without Electrocardiographic Gating by 256-Detector Row Computed Tomography, J Comput Assist Tomogr, 29(5):694-8.
25. Taguchi K, 2003, Temporal resolution and the evaluation of candidate algorithms for four-dimensional CT, Med. Phys. 30(4):640-50.
26. Zamyatin A, Taguchi K, Silver M, 2005, Experimental Reconstruction Algorithm for 256-slice Cone-beam Helical CT, Present

† The research and development of 4D-CT is performed in cooperation with NEDO, Japan (New Energy & Industrial Technology Development Organization) and the National Institute of Radiological Sciences, Japan.

† 256 Detector image courtesy of: National Institute of Radiological Sciences, Tokyo Women's Medical University, Jikei University School of Medicine, University of Fukui.

TOSHIBA AMERICA MEDICAL SYSTEMS, INC.

2441 Michelle Drive, Tustin CA 92780

(800) 421-1968

www.medical.toshiba.com

CTWP1058US