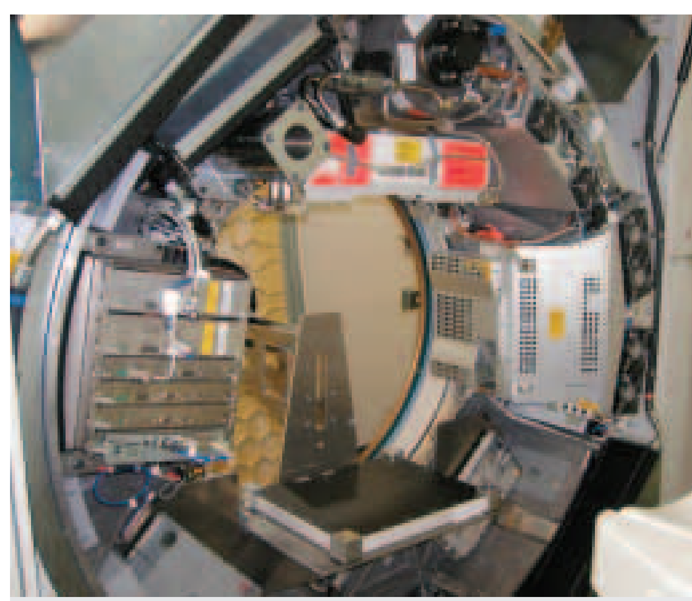
Volume CT with Flat Panel Detectors

During the past six years multi-slice CT (MSCT) has witnessed a significant increase in performance. Additional clinical benefit can be expected by area detectors large enough to cover entire organs in one rotation. The principles of volumetric scanning and potential clinical applications can be evaluated with flat panel technology.

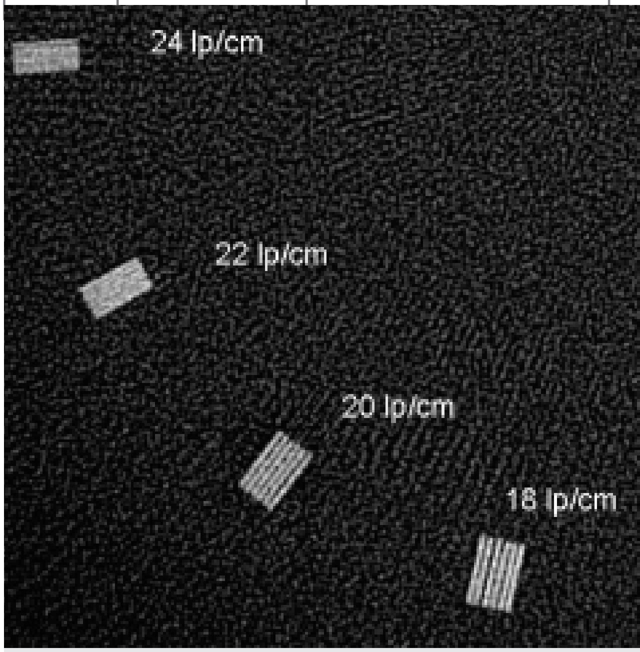
By Thomas Flohr, Ph.D., Michael Grasruck, Ph.D., Karl Stierstorfer, Ph.D., Stefan Popescu, Ph.D., and Christoph Süß, Ph.D., Siemens Medical Solutions, CT Engineering, Forchheim, Germany

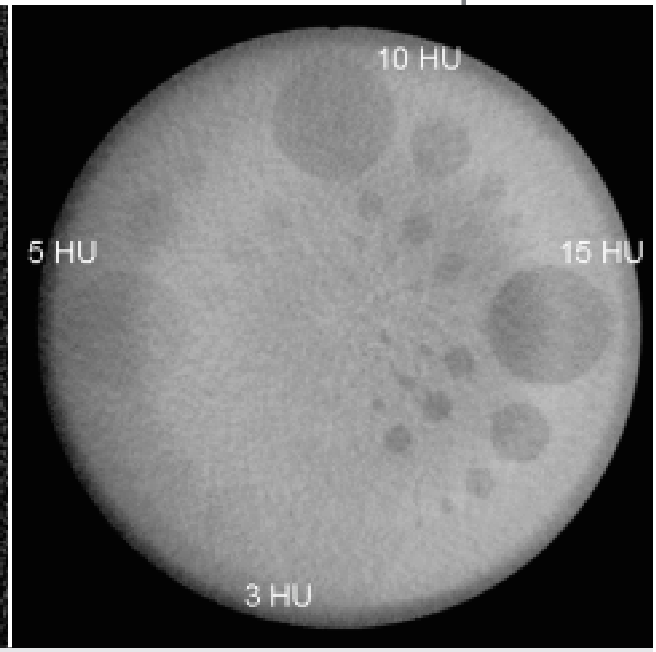
The introduction of four-slice CT in 1998 constituted a fundamental evolutionary step in the development and ongoing refinement of CT imaging techniques. Improved longitudinal resolution went hand in hand with faster volume coverage, considerably reduced examination times and better utilization of the available X-ray power. Multi-slice CT (MSCT) also dramatically expanded into areas previously considered beyond the scope of third-generation CT scanners based on the mechanical rotation of X-ray tube and detector, such as cardiac imaging with the addition of ECG gating capability. During the past six years we have witnessed a significant increase in the performance of MSCT systems, with the number of simultaneously acquired slices as the most important performance characteristics. The generation of four-slice CT systems was quickly followed by six-slice, eight-slice, 16-slice and finally 64-slice CT scanners, which were introduced in late 2003. The goal of isotropic spatial resolution for routine applications was within reach for MSCT with up to eight slices, yet coverage was limited. 16-slice CT for the first time allowed to cover substantial anatomical volumes, such as the entire thorax and abdomen, with isotropic submillimeter resolution in short



[1] Prototype of an area detector CT scanner based on a SOMATOM Sensation gantry with modified Akron tube (anode angle 16°) and an a-Si detector with CsI scintillator plate.

The information about this product is preliminary. The product is under development and is not commercially available in the U.S.A., and its future availability cannot be assured.





[2] Axial scan of a high-resolution phantom acquired with the flat panel CT prototype, demonstrating spatial resolution up to 22 line pairs per cm which corresponds to 230 µm object size.

[3] Axial scan of a low-contrast phantom acquired with the flat panel CT prototype, demonstrating low contrast resolution down to 5 HU.

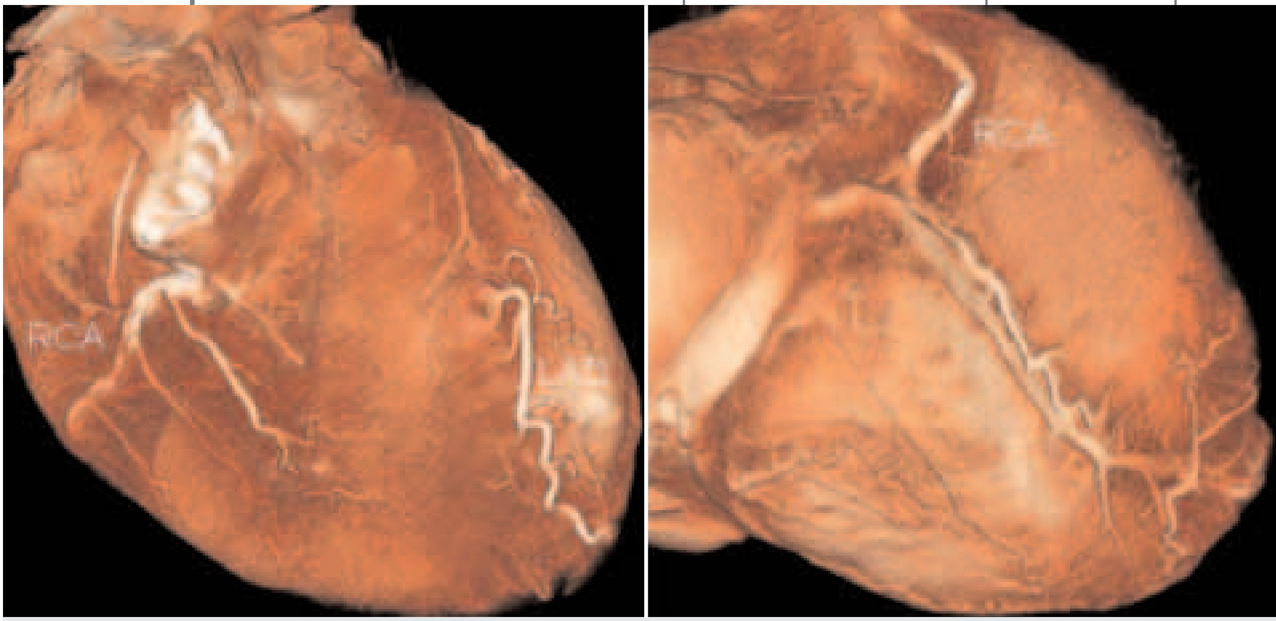
breath-hold times. With the introduction of 16-slice CT, a volume coverage speed of up to 48 mm/s could be achieved with submillimeter slices, which proved to be sufficient for the vast majority of clinical applications. For the new generation of 64-slice CT scanners, clinical progress can more likely be expected from further improved spatial and temporal resolution rather than from a mere increase in the volume coverage speed. Hence, innovative approaches such as refined z-sampling techniques enabled by a periodic motion of the focal spot in the z-direction (z-Sharp Technology™, SOMATOM® Sensation 64) have been developed to further enhance longitudinal resolution and image quality in clinical routine.

Increased Volume Coverage

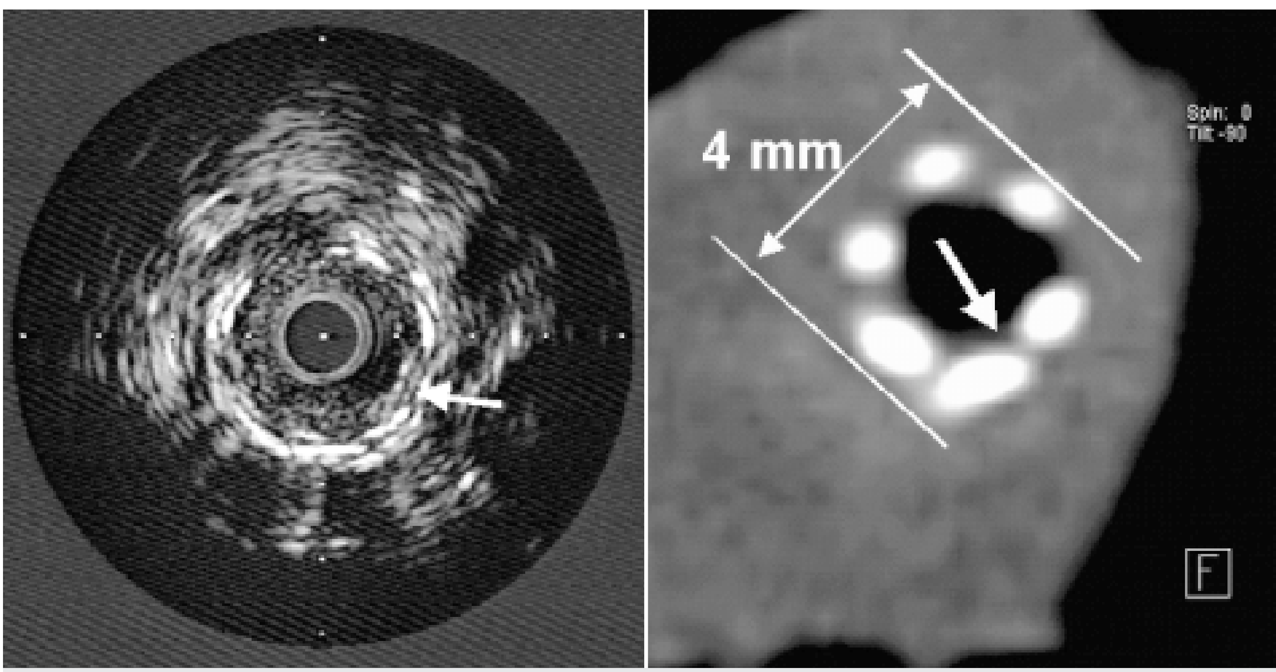
As soon as all relevant examinations can be performed in a comfortable breath-hold of not more than ten seconds, a further increase of the slice number will not provide significant clinical benefit. The trend towards a larger number of slices in the future will therefore not be driven by the need to increase scan speed in spiral acquisition modes, but rather by the desire to increase volume coverage in non-spiral dynamic acquisitions, e. g. by the introduction of area detectors large enough to cover entire organs, such as the heart, the kidneys or the brain, in one axial scan (~ 120 mm scan range). With these systems, dynamic volume scanning would become feasible, opening up a whole spectrum of new applications, such as functional or volume perfusion studies. Area detector technology is currently under development, but no commercially available system so far fulfills the high requirements of medical CT with regard to contrast resolution and fast data readout. Nevertheless, the prin-

[4] Multiplanar reformation of an inner-ear specimen with a stapes prosthesis scanned with the flat panel CT prototype. 0.25-mm isotropic resolution enables excellent detail visualization. (Image courtesy of Dr. Rajiv Gupta, MGH, Boston, MA, U.S.A.).

The information about this product is preliminary. The product is under development and is not commercially available in the U.S.A., and its future availability cannot be assured.



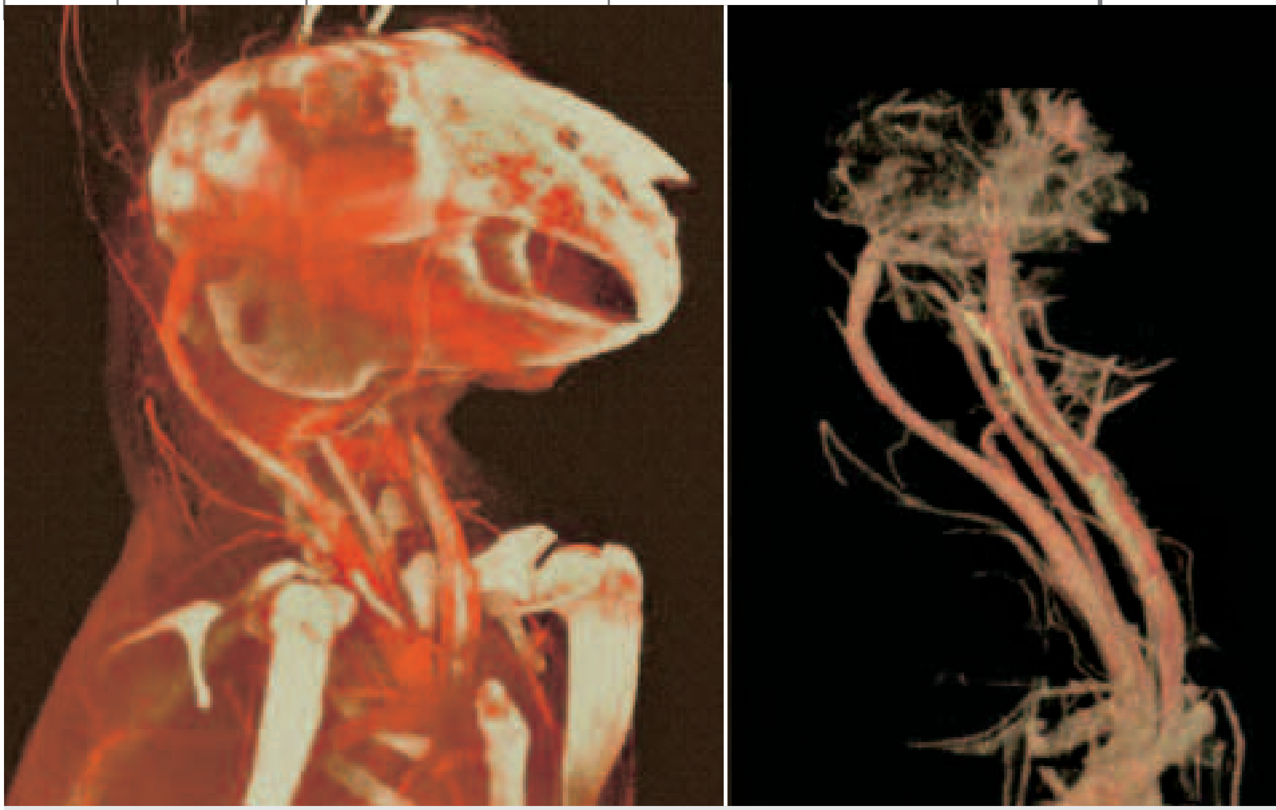
[5] Volume-rendered display of a stationary heart specimen scanned with the flat panel CT prototype. 0.25-mm isotropic resolution enables exquisite delineation of small side branches of the contrast-filled coronary artery tree. (Images courtesy of Dr. U. J. Schoepf, MUSC, Charleston, SC, U.S.A.).



[6] Ex-vivo study of a small in-stent hyperplasia in the distal part of a LAD stent. The finding has been confirmed by intravascular ultrasound (IVUS). (Images courtesy of Dr. Rajiv Gupta, MGH, Boston, MA, U.S.A.).

ciples of volumetric CT scanning and potential clinical applications can be evaluated with prototype systems using CsI-aSi flat panel detector technology originally intended for conventional catheter angiography. Figure 1 shows a prototype of such an area detector CT system, based on a SOMATOM Sensation 16 gantry. The system has been developed in collaboration with the Massachusetts General Hospital (MGH), Boston, MA. It uses a 40 x 30 cm flat panel detector (Varian Paxscan 4030CB), consisting of a matrix of 2048 x 1536 detector elements with a pixel size of 194 x 194 µm. In the current configuration of the panel 2 x 2 pixels are binned, resulting in 388 x 388 µm effective pixel size. A modified conventional X-ray tube with wide anode angle (16°) and small focal spot (0.5 mm) is used to illuminate the detector. Currently a frame rate of 30 frames per second can be achieved. This results in acquisition times of 20 seconds if 600 projections are to be acquired. Both the high intrinsic signal lag as well as limitations in the acquisition

The information about this product is preliminary. The product is under development and is not commercially available in the U.S.A., and its future availability cannot be assured.



[7] CTA of the head and neck of a rabbit, scanned with the flat panel CT prototype. (Images courtesy of Dr. Rajiv Gupta, MGH, Boston, MA, U.S.A).

electronics limit the frame rates to values at least one order of magnitude smaller than typically required for CT. Short gantry rotation times < 0.5 s, which are a prerequisite for successful examination of moving organs such as the heart, are therefore still beyond the scope of such systems. Spatial resolution is excellent though due to the small detector pixel size. The prototype provides isotropic spatial resolution of approximately 250 x 250 x 250 µm in a field of measurement of 25 cm diameter and 18 cm length along the z-axis. Figure 2 shows an axial scan of a high-resolution phantom acquired with the prototype scanner, demonstrating spatial resolution of up to 22 line pairs per cm which corresponds to 230 µm object size. An antiscatter grid consisting of lead leaves which are oriented towards the focal spot is used for reduction of scattered radiation. With a novel dynamic gain-switching mode enabling a useable dynamic range of up to 18 bit, low-contrast detectability has been significantly enhanced. Small contrast differences down to 5 HU can be differentiated (see the image of a low-contrast phantom in Figure 3).

Potential Clinical Applications

Improved low-contrast detectability is an important step on the way towards expanding the application spectrum of such a system from mere high-contrast scanning to general radiology CT applications. Intracranial haemorrhage, for example, could be reliably detected. In a preclinical installation at the MGH in Boston, MA, potential clinical applications of a flat panel volume CT system are currently being evaluated. The application spectrum ranges from ultrahigh resolution bone imaging to dynamic CT angiographic studies and functional examinations. Inner-ear imaging can substantially benefit from the increased spatial resolution. Figure 4 shows an example of a scan of an inner-ear specimen with a stapes prosthesis. Figure 5 shows VRTs of a contrast-filled heart specimen demonstrating excellent spatial resolution, which enables visualization of even very small side branches of the coronary artery tree. Potentially, the lumen of small stents in the coronary arteries can be evaluated, and in-stent restenosis can be reliably detected. Figure 6 shows an ex-vivo study of a small in-stent hyperplasia in the distal part of a stent in the left ascending coronary artery (LAD). The finding has been confirmed by intravascular ultrasound (IVUS). Other interesting applications for volume CT include dynamic CTA examinations, e. g. of the carotids and the circle of Willis. Figure 7 shows an example of a CTA of the head and neck of a living rabbit.

Conclusion

The combination of area detectors that provide sufficient image quality with fast gantry rotation speeds will be a promising technical concept for medical CT systems. Yet, a potential increase in spatial resolution to the level of flat panel CT will be associated with increased dose demands, and the clinical benefit has to be carefully considered in light of the applied patient dose.

The information about this product is preliminary. The product is under development and is not commercially available in the U.S.A., and its future availability cannot be assured.