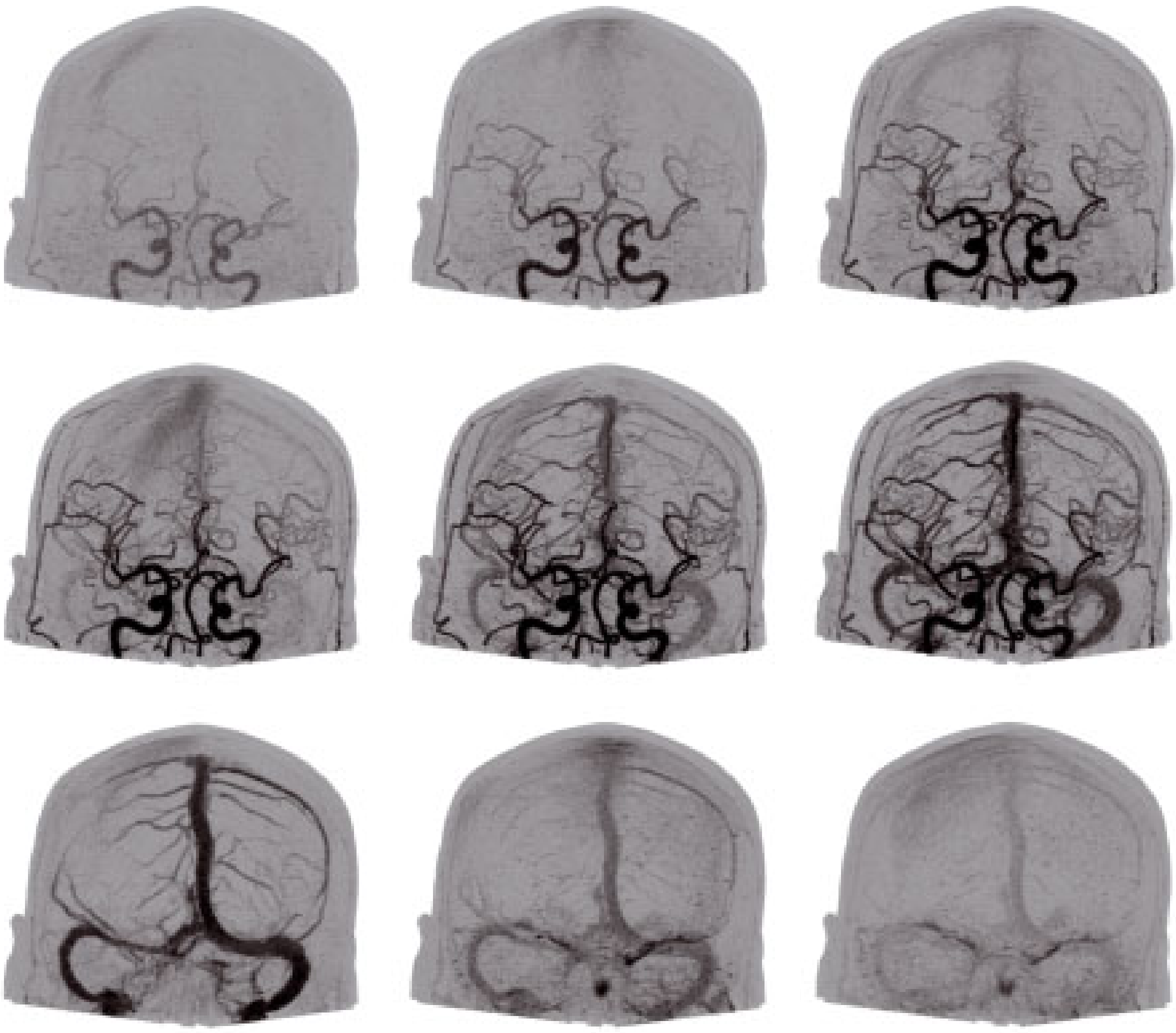
€ 7,50

TOSHIBA MEDICAL SYSTEMS JOURNAL

TOSHIBA

Leading Innovation



Dynamic volume images made with Toshiba's Aquilion ONE

SPECIAL ISSUE 2008

DYNAMIC VOLUME IMAGING

TOSHIBA MEDICAL SYSTEMS

Imprint

Publisher:
TOSHIBA Medical Systems Europe B.V.,
Zilverstraat 1, NL-2718 RP Zoetermeer
Tel.: +31 79 368 92 22
Fax: +31 79 368 94 44
Email: visions@tmse.nl

Editor-in-chief: Jack Hoogendoorn

Editorial review:
CT: Dr Jörg Blobel
MR: Faiza Admiraal-Behloul
X-ray: Bob Eastick
Ultrasound: Dr Jörg Schlegel

Printing: VVA, Düsseldorf

Subscription Service:
Tel.: +31 79 368 92 71
Email: visions@tmse.nl

TOSHIBA Infoline:
Austria: +43 2236 616 23
Germany: +49 2131 180 91 23
Belgium: +32 3 3262 323
Spain: +34 914 9058 50
France: +33 1 47 2825 00
Italy: +39 06 520771
Portugal: +35 1 21 414 7490
United Kingdom: +44 1293 653700
Russia: + 7 095 975 2497
Switzerland: +41 1 929 6666
The Netherlands & other countries:
+31 79 368 99 99
Head Office Europe: +31 79 368 92 22

Dear reader,

The major advantage of computed tomography over other imaging modalities is the excellent spatial resolution of anatomical structures down to the sub-millimeter range.

The disadvantage of CT has been – to date – its limitation with regard to functional diagnostics. With its volume detector of 16 cm width, the Aquilion ONE overcomes this disadvantage. A new CT generation will visualize the functioning of entire organs, for example the heart or the brain, within less than half a second scan time and with a voxel resolution smaller than 0.5 mm. Aquilion ONE rings in the era of dynamic volume computed tomography.

Over the next few months, clinical research and industry will jointly develop new dynamic volume CT diagnostic strategies. The following articles provide a first impression of the methodological principles and initial clinical experiences.

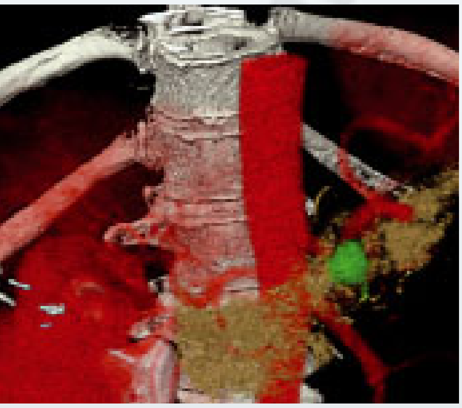
The future of CT has just begun!

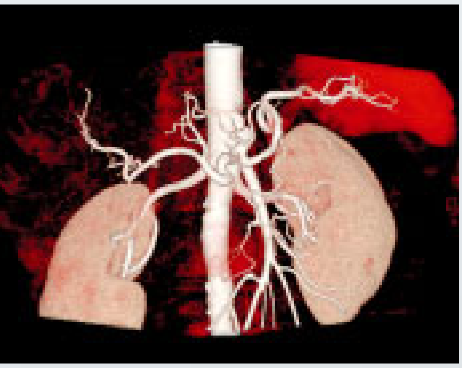
PD Dr P Rogalla
Director CT Division
Charité Campus Mitte
Berlin, Germany

Dr J Blobel
Chief Clinical Science
TOSHIBA Medical Systems Co.
Tokyo, Japan

Special: Dynamic Volume Imaging

Charité, Berlin in November 2007: positioning, installation and initial operation of the new Aquilion ONE as well as the experience with the first patients has demonstrated that the new dynamic volume CT scanner opens up new vistas in diagnostic computed tomography. The results surpassed all expectations. Particularly in cardiac imaging the radiation dose can be reduced significantly without any loss in image quality. *Page 15*



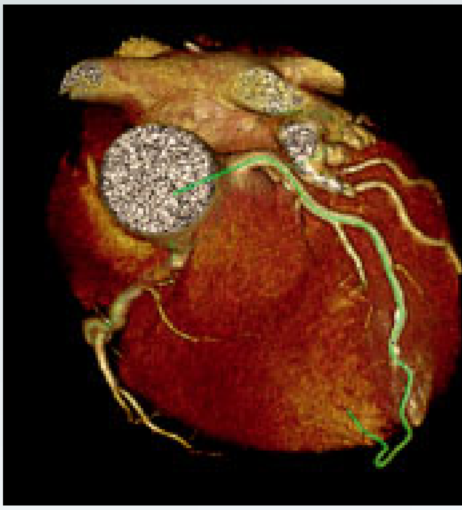


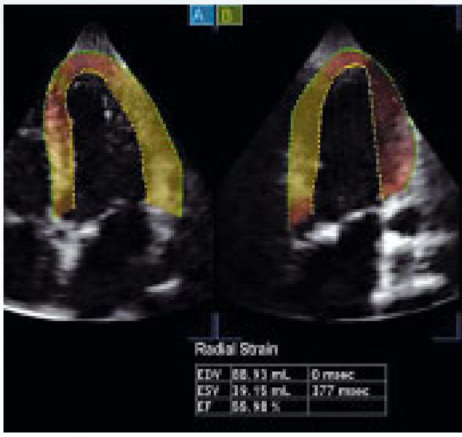
The spatial image voxels and the data acquisition time are all elements of dynamic volume CT. Even when looking at dose equivalency, high and low contrast resolution of the Aquilion ONE, the first dynamic volume CT scanner, compare favorably with the results of the Aquilion 64. Compared with the helical scan of a 64 MSCT and its standard pitch of 0.2 for cardiac scanning, the lack of oversampling in dynamic volume CT reduces radiation exposure by 80%. *Page 20*

MRI

Ultrasound

A further, altogether new area of application in non-invasive diagnostic cardiac imaging is myocardial perfusion imaging by computed tomography. In dynamic scanning mode the CT scanner is able to record the volume data of the entire heart, either continuously during a specific interval or intermittently in certain time intervals.
Page 24





Artida's basic philosophy centers on advanced transducer design to provide better data, faster and more flexible signal processing to extract more information more quickly. The final result is improved clinical performance and a host of tools that provide new ways to assess 2D and 4D ultrasound data. Page 44

R Irwan
H B K de Vries
L Bouwman
H Zomer

The History of Computed Tomography

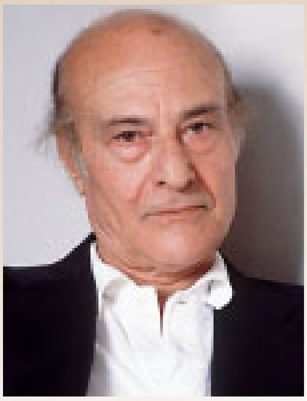


Fig. 1a: Allan Cormack (with permission of the Nobel Prize Foundation)

Fig. 1b: Godfrey Hounsfield (with permission of the Nobel Prize Foundation)

Introduction

Computed tomography (CT) scanners have undergone continuous development and gained widespread acceptance as one of the most innovative medical imaging modalities to date. The most significant application of CT lies in the diagnosis of neurological, cardiological and oncological disorders.

The art of CT is constantly evolving and the last years have seen new systems with more and more row detectors. These CTs are able to increase both scanning speed and image quality compared to single-row systems.

The following brief history of CT technology, starting from the early days, focuses on the first Toshiba CT scanners and the development of the detector systems which to a great extent determine image quality.

Discussion of clinical applications or fundamental technical details is beyond the scope of this overview and can be found in a number of texts[1-3] and the references therein.

The development of CT

For the first fifty years of radiology, the primary examination involved creating an image by focusing X-rays through the body part of interest and directly onto a single piece of film inside a special cassette. In the earliest days, a head X-ray could require up to eleven minutes of exposure time and the patients had to hold the cassettes themselves. Today, X-ray images are made in milliseconds and the X-ray dose currently used is as little as 2% of what was used for that eleven minute head exam 100 years ago.

Early development of CT

Allan Cormack and Godfrey Hounsfield investigated independently how the limitations of X-rays could be tackled to reconstruct an accurate cross-section of an irregularly shaped object. In 1979, both Cormack and Hounsfield received the Nobel Prize for physiology and medicine for the development of CT[4].

Seven years before being awarded the Nobel Prize, Hounsfield had patented the first CT scanner. He is considered to be the father of CT since he developed a method which is the foundation of today's CT, the EMI (Electrical and Musical Industry) scanner. This prototype, originally intended for examinations of the head, took hours to scan the first patient and five minutes to acquire each image.

Development of Toshiba CT

The direct association of Toshiba with CT dates back to the installation of the first EMI head scanner in Japan in August of 1975 at Tokyo Women's Medical College[6]. Business collaboration between Toshiba Medical Systems and EMI Medical, the original

Fig. 2: The second-generation CT scanner (TCT-35A), launched in 1977, was based on translation/rotation technology and had eight detectors.

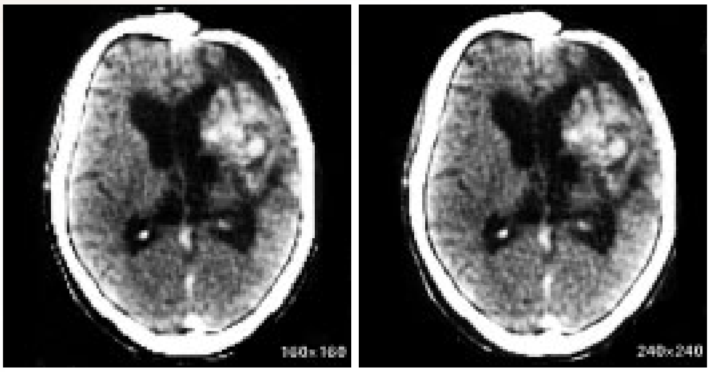
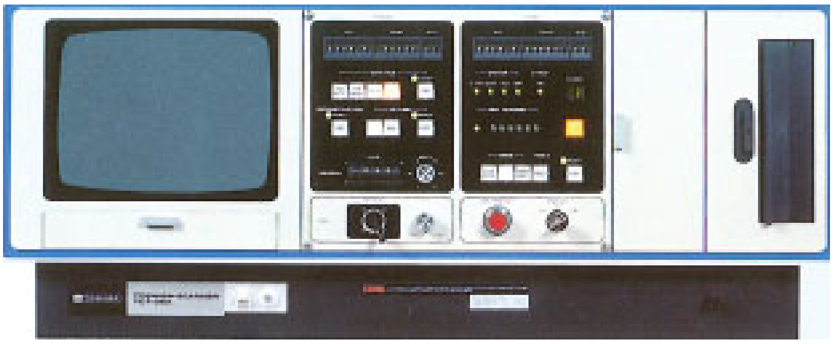


Fig. 3: First brain CT images of 160 x 160 matrix (left) and 240 x 240 (right) which took 45 -130 seconds to reconstruct. They were both of 5 mm slice width.

Fig. 4: One of the first Toshiba CT consoles



inventors of CT, continued but soon Toshiba began to manufacture its own brain and whole-body scanners. The development of Toshiba CT scanners can be categorized into three main phases:

1. axial scanning
2. helical scanning
3. volume scanning.

Axial scanning

Axial (often called "step-and-shoot") scanning characterizes the first Toshiba CT generations in which a slice was acquired from a fixed tube position.

While the single detector CT scanner with translation/rotation geometry represents the first-generation CT, the second-generation CT scanner had eight detectors with the same geometry as the first generation. This translation/rotation geometry will be explained in more detail below.

Figure 2 shows a Toshiba second-generation CT scanner, the TCT-35A, launched in 1977. It could produce a matrix of 160 x 160 or optionally 240 x 240 (Fig. 3 left and right, respectively). The physicians were fascinated by the ability to see the soft tissue structures of the brain including the black ventricles.

Figure 4 shows one of the first CT consoles which pioneered image reconstruction and offered the first remote control between a Toshiba CT scanner and the computer server.

A year later, in 1978, Toshiba's accumulation of expertise was demonstrated by the launch of a whole-body CT scanner, the TCT-20A (Fig. 5), which marked the beginning of successful clinical practice. The translation/rotation technology was replaced by a rotation/rotation configuration - the third generation of CT scanners. This technology was developed to reduce scan times to approx. 1.8-6 seconds.

Furthermore, in this third generation Toshiba also introduced the worldwide first direct magnification system to vary the distances between the X-ray tube/patient and patient/detectors according to the size of the part of the anatomy being scanned (Fig. 6). The resulting image was much better than that produced by scanners of previous generations.

Helical scanning

In the early 1980s, Toshiba patented an innovative scan technology called helical (or spiral) scanning where true continuous scanning has at last been achieved[7]. This remarkable innovation made available a number of clinical applications that had

Fig. 5: Toshiba's third-generation CT scanner (TCT-20A) based on rotation/ rotation technology with 1.8-6 seconds scan time

Fig. 6: Another third-generation Toshiba whole-body CT scanner (TCT 60A) launched in 1978 which incorporated the principle of geometric magnification by changing the source/patient and patient/detector distance.

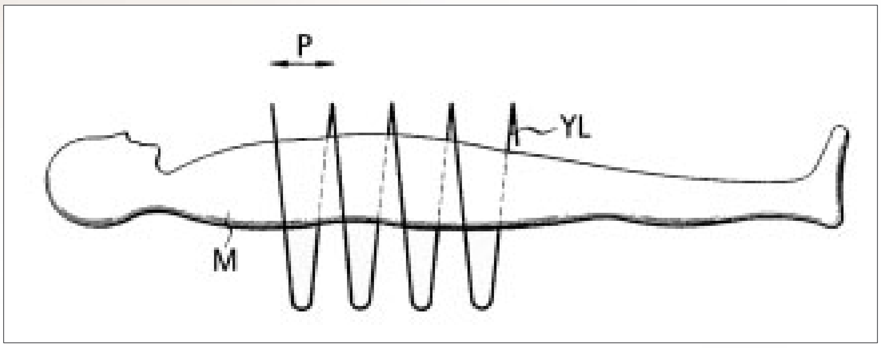


Fig. 7: The basic principle of helical scanning meant a quantum leap in the advance of CT technology patented by Mori[6] in the early 1980s.

been inaccessible to conventional axial CT scanners. Helical scanning technology is the basis of most commercially available CT scanners today.

During a helical scan, the table moves at a constant speed as the X-ray tube performs a continuous rotating scan as demonstrated in Figure 7.

The large volume of data gathered enables a large area of the body to be examined during a single breath-hold. This produces sharper images, including 3D and MPR, as well as improved diagnostic accuracy.

A slip-ring is employed to transmit power between the gantry and the rotating X-ray high-voltage generator assembly. Figure 8 shows early high-voltage tests of a slip-ring gantry at Toshiba Medical Systems Center. Rotational tests were successful at speeds of up to two revolutions per second.

Fourth-generation CT was characterized by a design using a stationary detector ring and rotating X-ray tube. The TCT-900S/x (Fig. 9) was the first fourth-generation Toshiba helical scanner being able to combine high-speed scanning with rapid back and forth table top movement.

In addition, not only interscan delays are eliminated by using nutate/rotate geometry but also a spatial resolution of 0.35 mm has been achieved. Nutation is a slight irregular motion in the axis of rotation of an object as the X-ray tube is positioned outside the dectector ring (Fig. 10). This nutation/rotation configuration reduces the number of detectors and the radius of the detector ring. Furthermore, since the effect of focus size on spatial resolution is minimized, a large focal spot can be used to deliver a high X-ray dose, yielding high-quality images.

Dynamic volume CT

Although helical scanning was an innovative breakthrough in CT scanning, Toshiba continues to be the leading innovator in CT technology by developing the dynamic volume CT scanner (Fig. 11). An issue of helical scanning was that the patient table must be moved to scan the entire heart, which

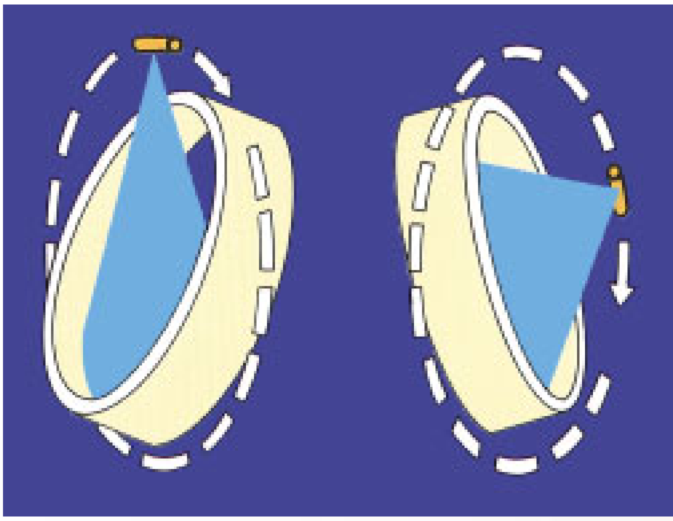
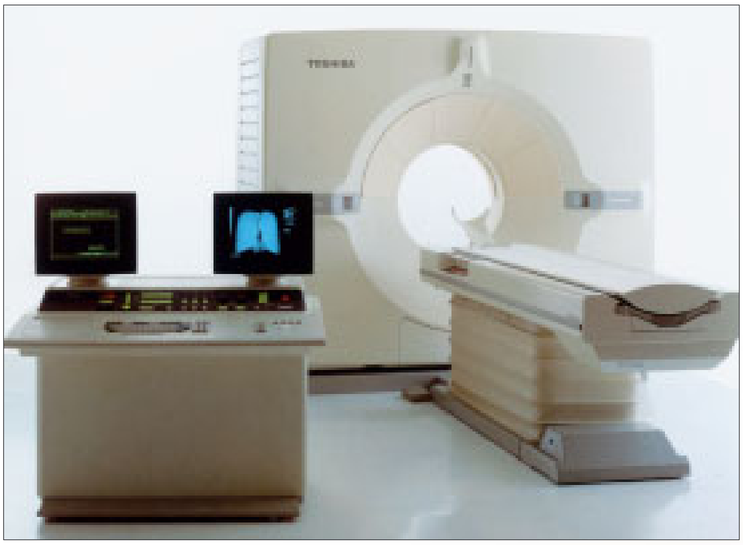


Fig. 8: High voltage tests on the first slip-ring technology. Speeds up to two revolutions per second were achieved[6].

Fig. 9: A fourth-generation CT helical scanner (TCT-900S/x) which eliminates interscan delays by the use of nutate/rotate geometry and slip-ring technology



requires additional time. This may lead to a mismatch of temporal phases between the upper and lower ends of the scan range.

Dynamic volume CT permits the entire heart to be examined without the need for the helical scan. In other words, the entire heart can be captured in a single rotation for coronary analysis, or over a single heartbeat to include complete functional diagnosis. Moreover, volume scanning allows acquisition of multiple low-dose volume scans of the entire brain during contrast infusion to provide whole brain perfusion and whole brain dynamic vasculair analysis in one examination.

Detectors

Early development

The detector is one of the most important parts in a CT system as it determines image resolution and acquisition speed. The X-ray tube and the detector are positioned opposite to each other. In the first- and second-generation CT scanners (see also Fig. 5), the detectors and the X-ray tube move through a series of linear translates and rotates around the patient's head as demonstrated in Fig. 12. A number of detectors is situated directly opposite the X-ray tube. The detectors and the X-ray tube move through a series of 30 linear traverses by 6° between each traverse until the full 180° rotation is complete.

The detector acquires the attenuated X-rays and converts them to visible light, which in turn is converted into digital signals by high-speed electronics. Powerful computer create high-resolution CT images in real-time.

Development of Toshiba detectors for multislice CT

From the commercial point of view, as the number of rows increases, development work becomes both more difficult and more expensive. However, the increase in the number of rows was unavoidable due to the following needs[8]:

- higher spatial resolution
- higher time resolution (speed to convert X-rays to electronic signals)
- better low contrast resolution
- lower exposure dose.

Toshiba has been able to achieve the minimum slice thickness of the detector of 0.5 mm which determines the resolution in the longitudinal direction. Transmitted X-rays are detected and converted into electrical signals by the selectable slice-thickness multi-row detector (SSMD).

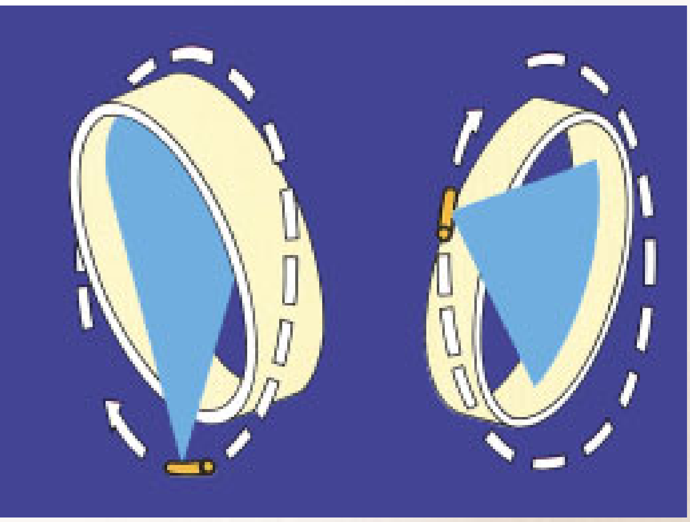


Fig. 10: Nutation/rotation configuration. The X-ray tube (yellow) is placed outside the detector ring.

Fig. 11: The volume scanner Aquilion ONE, which was introduced at RSNA 2007, is able to scan the entire heart or head with a single rotation.

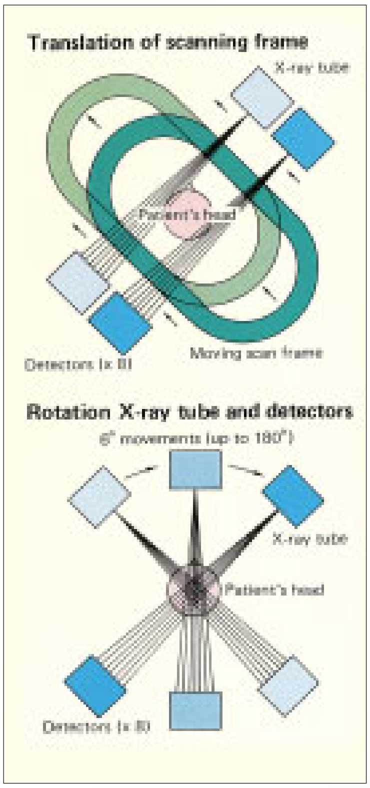
The 4-slice SSMD had some advantages over the single-slice detector in terms of reduced penumbra (Fig. 13) and therefore exposure dose. However, the unused penumbra continued to be an issue as the patient was still exposed to unnecessary X-rays.

Therefore, 8-slice and 16-slice SSMD systems were introduced to reduce X-ray radiation further by approximately 20% and 40%, respectively[3]. The key for exposure reduction in the development of X-ray CT systems is to improve detector efficiency. All manufacturers have therefore been striving to develop new materials for scintillators. Toshiba is also exploring new materials for its next-generation detectors to improve efficiency by approximately 40% compared to conventional scintillators. The efficiency of Toshiba's current detector surpasses that of competitors. Inefficient scintillators lead to a deterioration of image quality each time the number of detector rows is increased and slice thickness is reduced.

In clinical applications, the stent lumen was virtually invisible in a 8-slice system. Improved visualization using 16-slice system was reported, in particular in stents with either a large diameter or thinner struts[9,10].

In 2003, the first 32-slice SSMD system (Aquilion 32) was introduced which strived for further reductions in X-ray exposure and further improvements in patient- and user-friendliness in CT examinations. Like the Aquilion 16, this system is a multislice helical CT that supports whole-body scanning.

One year later, the first 64-slice SSMD system (Aquilion 64) was launched. With a 64-slice system the entire heart can be covered in a few heartbeats which increased temporal resolution and lowered the dose compared to previous systems.



320-slice detector

For volume scanning, 320 detector rings (Fig. 14) were introduced which produce isotropic resolution of 0.35 mm voxels. The major benefit of 320-slice CT is the increased speed of volume coverage.

This latest technology has demonstrated the potential to significantly reduce radiation exposure by eliminating the

Fig. 12: Detectors are positioned opposite to the X-ray tube. The early technology where the tube and detectors move in a linear fashion across the patient (top) and rotate around the patient (bottom) by each traverse (see also Fig. 5).

requirement for a helical examination in both cardiac CT angiography (see related article in this issue) and whole-brain perfusion studies for the evaluation of stroke.

This allows large volumes (up to 16 cm coverage) to be scanned within one single rotation following intravenous administration of contrast agent; this has particularly benefitted CT angiography techniques - which rely heavily on precise timing to ensure good demonstration of arteries.

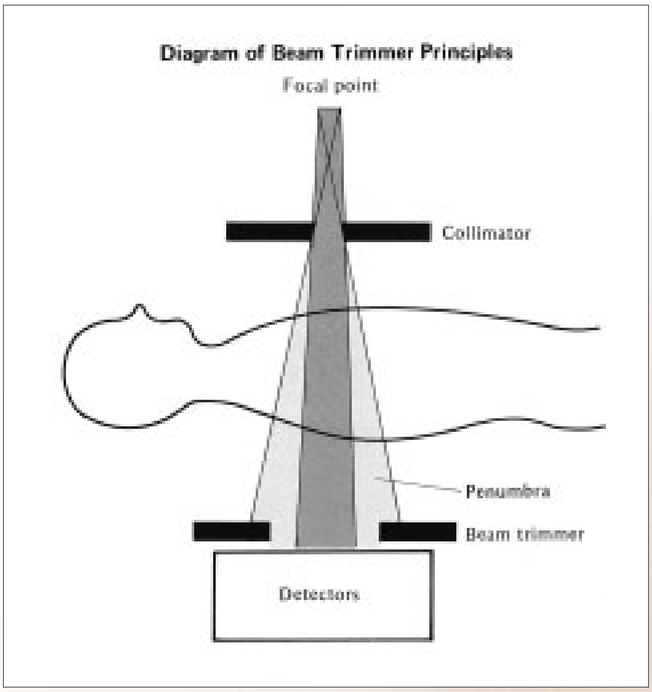
Last but not least, Toshiba has developed and released image reconstruction techniques (MUSCOT, TCOT and ConeXact) optimized for each CT generation - from 4- to 16- and 64-row CTs as well as the 320-row CT. We are pleased to say that the image quality of our CT is considered the best in global markets such as Japan, USA and Europe. For the past ten years, an image quality issue for CT has been to minimize the cone angle effect associated with the increase in the number of detector rows. We are therefore proud that the release of the world's first dynamic volume CT Aquilion ONE™ has proven our image reconstruction technique is the world's most advanced technology.

Fig. 14: Recently introduced 320 detector rings (0.5 mm) cover a 16 cm object range and are able to scan the whole heart in one rotation.

Summary

We hope we have given you a brief overview of the history of CT in terms of the fundamental research, evolution and latest development, although it is impossible to cover all aspects in detail. In short, CT continues to thrive on innovation and to broaden its scope, apparently without limit. The heart and brain of computed tomography, however, remains the work by the scientists mentioned above.

Fig. 13: Penumbra has been an ongoing issue in the development of multislice CT



References
1 S. Saini, GD Rubin, MK Kalra (eds.), "MDCT, a practical approach", Springer, ISBN 88-470-0412-5.
2 MS Budoff, S Achenbach, J Narula (eds.), "Atlas of Cardiovascular CT", Springer, ISBN 978-1-57340-267-5
3 I Mori, T Suzuki, "Development of Advanced Multislice CT scanner Aquilion", eMedical Review.
4 http://nobelprize.org/nobel_prizes/medicine/laureates/1979/
5 GN Hounsfield, "Penetrating radiation examining apparatus having a scanning collimator", U.S. Patent No. 3,866,047, filed in 1973, issued in 1975.
6 I Mori, "Computerized Tomographic Apparatus Utilizing a Radiation Source. U.S. Patent No. 4,630,202, filed in 1983, issued in 1986.
7 S Makino, JF More, K Saito, CR Smith, "Development of an Advanced CT scanner", Medical Review No. 19, 1988.
8 M Okumura, M Tamatani, K Igarashi, "Development of x-ray detector for multislice CT with 0.5 mm slice thickness and 0.5 second revolution", Proc. SPIE 4682, 2002.
9 JD Schuif, JJ Bax, JW Jukema et al, "Feasibility of assesment of coronary stent patency using 16-slice CT", Am J Cardiology, 94:427-30, 2004.
10 F Cadermartiri, JD Schuijf, NR Mollet, P Malagutti, G Runza, JJ Bax, PJ de Feyter, "Multislice CT coronary angiography: how to do it and what is the current clinical performance?", European J of Nuc Med and Mol Imaging, 32(11), 2005.

Acknowledgment
We thank Hans Baartman for his valuable comments.

Toshiba Medical Systems Europe BV,
Zilverstraat 1
2718 RP Zoetermeer
The Netherlands

Installation of Aquilion ONE™

The Aquilion ONE dynamic volume CT, from Toshiba Medical Systems, has most recently been installed in two leading academic hospitals in Europe. With systems already in use in Japan, the USA and Canada and further orders received from all over the world, the Aquilion ONE is already starting to create new global standards in imaging diagnostics. Leiden University Medical Centre (LUMC) in Leiden, the Netherlands, and the Charité University Hospital in Berlin, Germany, were the first in Europe to acquire this new technology.

During the installation of the Aquilion ONE in Leiden, VISIONS talked to Claude Moinier, Service Support Manager, Kees Kalkman, Senior Product Specialist of the Technical Support Group from Toshiba Medical Systems Europe and Koji Umehara, Deputy Manager CT Systems Division from Toshiba Medical Systems Corporation in Japan. They explained to VISIONS what was involved in installing the Aquilion ONE.

First installation of the Aquilion ONE in the Leiden University Medical Centre

Claude Moinier, Koji Umehara, Kees Kalkman (from left to right)

VISIONS: *LUMC is one of the first European hospitals to acquire the Aquilion ONE. What has prompted the decision to install the system?*

Claude Moinier: Providing outstanding regional, national and international medical services and research, LUMC is affiliated to Leiden University in The Netherlands. It has 867 beds, approximately 7000 staff and clinical departments in all medical specialities. The hospital acts as a tertiary referral centre for the northern part of the province of South Holland, as well as coordinating a wide range of research programmes in both clinical and basic medical research. LUMC holds an internationally recognised position as a centre of excellence in research. Its special units include neurosurgery, cardiothoracic surgery, neonatal and paediatric surgery and intensive care, paediatric oncology and a level I trauma centre. The wide area detector of the Aquilion ONE, being 16 cm, covering entire organs in just one rotation, allows clinicians to visualize flow and dynamic motion, giving not only morphological but functional information. Faster and more precise diagnostics for a wide range of applications are now in reach of clinicians and patients.

Kees Kalkman: LUMC and Toshiba Medical Systems have a long-standing relationship over many years. Having started with nuclear medicine, back in the 70s, this cooperation was extended several year ago to CT (computed tomography). The new Aquilion ONE CT system, which is being installed at the hospital, complements a 64-slice and a 16-slice CT, both of which are Toshiba scanners.

Koji Umehara: The hospital takes pride in providing the best possible quality regarding both medical technology and patient care. It committed eagerly to the state-of-the art Aquilion ONE CT, towards making further improvement to the hospital's (already excellent) record in quality and time of diagnosis, and to effect a further reduction in costs. LUMC was highly impressed by the system's advanced capabilities and fully confident in Toshiba's consistent support services.

VISIONS: *Are there any special considerations that need to be made before installation of the Aquilion ONE can begin?*

Kees Kalkman: Toshiba's installation team ensured that LUMC was well prepared to receive the new system. It goes without saying that this new technology requires specially trained engineers for installation and what's more important, to assure high-quality service. Therefore, we received extensive training in Japan. Also Japan supported the first European installation by sending their most skilled engineers, all to ensure that the new Aquilion ONE will run smoothly from day 1 onwards.

VISIONS: *How was the system transported to its operational site?*

Kees Kalkman: The Aquilion ONE was manoeuvred through the LUMC building and into the CT room with the aid of a crane. To facilitate transport and lifting, the Aquilion ONE has been designed with special winching hooks.

VISIONS: *The Aquilion ONE is more powerful than the present generation of CT scanners, is it also much bigger?*

Kees Kalkman: The system itself is very much comparable to our Aquilion 64 and Aquilion 16. However, due to a larger scannable range the Aquilion ONE requires a slightly larger working space.

Accurate testing of all CT scanner parameters is a crucial part of a good quality control programme. This is done using phantoms – these are cylindrical, water-filled structures used for calibrating CT (and MRI) systems to ensure the quality of images.

VISIONS: *What about the power requirements of the Aquilion ONE?*

Koji Umehara: Aquilion ONE is a significantly more powerful machine than presently available CT scanners. Both in diagnostic performance as well as in processing the big amount of clinical images. It

goes without saying that adequate capacity for dealing with the heat, generated by the powerful reconstruction units must be taken into consideration. The existing power supply and cooling capacity of the CT room at Leiden was examined when planning the machine installation and proved to be sufficient for the system.

The Aquilion ONE has been designed to be as energy efficient as possible. It reuses the kinetic energy produced in the breaking of rotations to reduce total energy consumption. This is known as an 'ecodrive' function and can help reduce the overall energy requirements.

VISIONS: *With these distinctive product features in mind, is the technical installation of the system also different?*

Koji Umehara: The installation time of the new Aquilion ONE has proved to be very similar to that for the Aquilion 64. A great deal of effort has been made to ensure that the Aquilion ONE is as easy and efficient to install as other Toshiba machines.

Claude Moinier: This is largely due to the fact that the installation design has deliberately been kept as close to the Aquilion 64 as possible. Toshiba Medical Systems not only considers the needs of end users of its systems in all stages of product development – the hospital's clinicians, technicians and patients - but also of the Toshiba service engineer as an integral part of the process. The faster and easier the system can be installed, the less investment is required by the customer. In addition, any margin for error is absolutely minimized. What's more the close resemblance in user interface not only facilitates interventions by service staff, but also assures that Toshiba customers can learn the scanning procedures on the Aquilion ONE in a considerable shorter period.

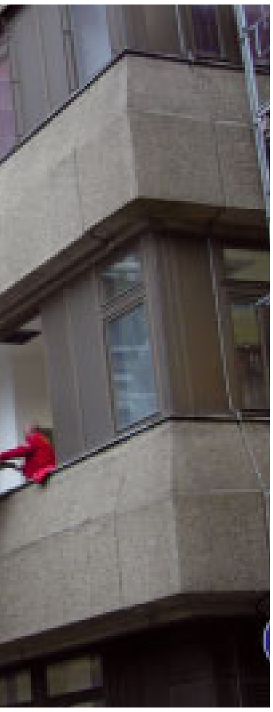
Koji Umehara: The installation has been kept as simple as possible through the use of well-labelled connections and one-fit-only connections. From the drawing board through every stage of development, Toshiba has considered the needs of the service engineer and, in-turn, optimized efficiency of installation.

VISIONS: *Are there any operational considerations with the Aquilion ONE which Toshiba's installation team helps prepare its customers for?*

Claude Moinier: There are a small number of operational differences with the Aquilion ONE which customers need to consider before installation is complete. Toshiba's installation team provides expert advice to ensure that every aspect of operation has been considered in setting up the system and integrating it seamlessly into daily use.

Kees Kalkman: Visualization of dynamic processes over a wide area, without the need to move the patient, will generate a large amount of clinical images which need to be reconstructed and visualized at high speeds. Toshiba has incorporated many more optical connections inside the machine to enable it to deliver data faster and with greater volume.

VISIONS: *Does the more complex internal architecture of the Aquilion ONE mean it is more difficult to integrate, operate and interact with?*



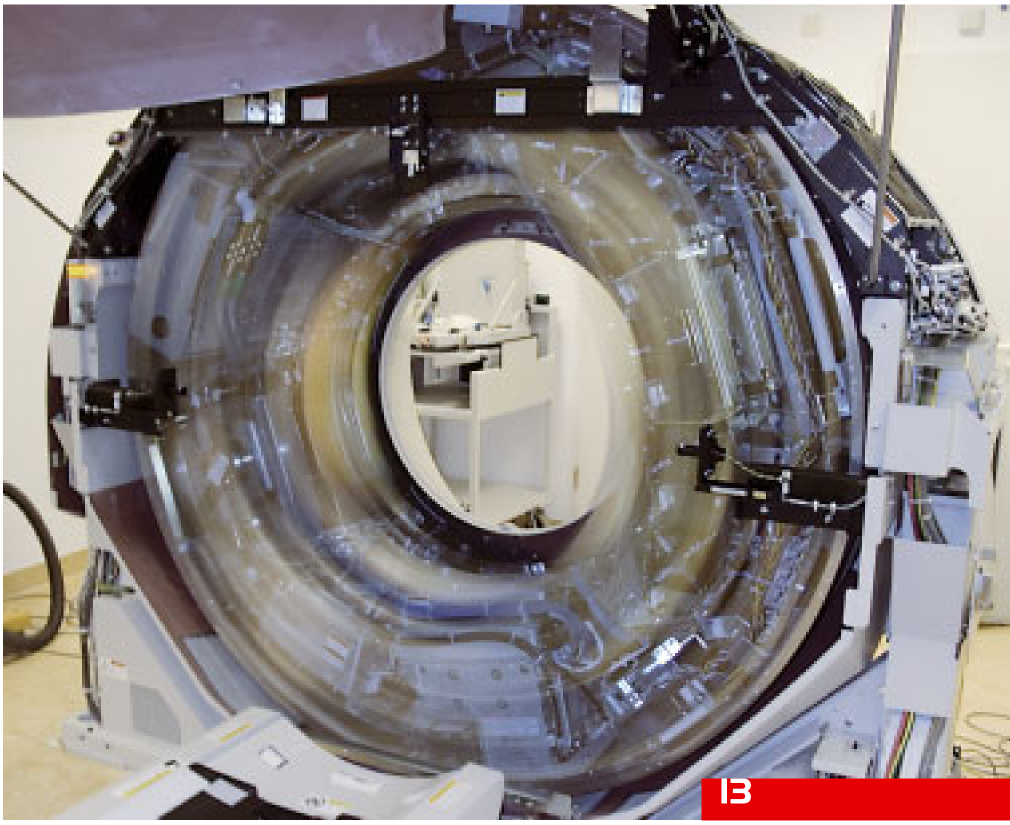
Step by step: installing the new CT at the University Hospital Charité in Berlin, Germany.

Claude Moinier: Absolutely not! The new Aquilion ONE is entirely geared towards PC compatibility, giving even more flexibility than previous systems. As mentioned earlier the operator interface is very very similar to the Aquilion 64. The image quality handling procedure for calibration and maintenance follows that of the Aquilion 64, too.

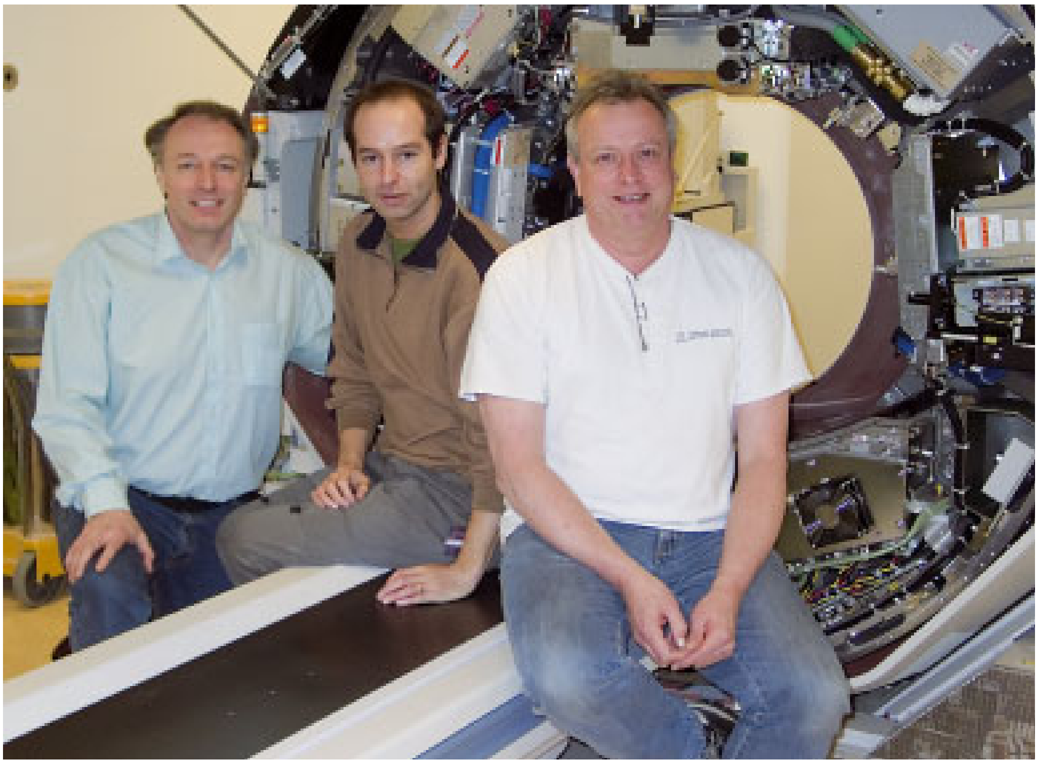
VISIONS: *Once the system is installed, is maintenance the same as the Aquilion 64?*

Claude Moinier: Some aspects are the same; most notably that Toshiba continues to provide a comprehensive technical support system, as it has done effectively at LUMC for many years. Toshiba's service team can help with solving any problems via remote access – as with the majority of our later CT systems. InnerVision is our remote diagnostic service which provides proactive support and quality assurance. The system periodically monitors our imaging equipment to ensure it is always delivering the clinical excellence required.

If a problem is detected, highly trained service staff of our "StandbYou" service are available to carry out online diagnostics to identify and resolve the issue. Experts are able to explore online solutions



The first test run of the Aquilion ONE



After the storm: the engineers proudly present their masterpiece at the Leiden University Medical Centre (LUMC), The Netherlands.

and frequently resolve them without the need for an on-site service.

Preventive measures mean less unscheduled downtime for the hospital. Automated predictive diagnostics alert Toshiba to a potential issue before it becomes a problem. Proactive monitoring helps minimize costly downtime and the need to reschedule examinations and helps in the long-term improvement of quality standards in our products.

Kees Kalkman: Toshiba offers various levels of maintenance for more security and insurance appropriate for the advanced science of the Aquilion ONE.

VISIONS: *Aside from effective installation and maintenance is there anything else which can ensure the longevity of the Aquilion ONE?*

Koji Umehara: Toshiba thinks ahead to the next five to ten years in product design and invests only in technology that has long-term prospects. This ensures that all our systems deliver optimal performance for the maximum time from installation to eventual replacement. The Aquilion ONE has been designed to be relatively easily upgradeable. All our systems are also developed with the same principle in mind.

VISIONS: *So installation of the Aquilion ONE is not just a distinct technical procedure for Toshiba, but part of a continuum of interactive and integrated service and development?*

Koji Umehara: My focus is on the CT business, including CT design interface with service, marketing and quality. An important part of my role is to relay our Aquilion ONE installation experiences at LUMC to Toshiba Medical Systems global headquarters in Japan. Installation issues are a critical part of product and service design and through this, and many other channels, our expertise can be honed further into the future.

Claude Moinier: At Toshiba, a CT installation is not carried out by an isolated team. The European Service Group delivers training, education, service plans and if necessary troubleshooting. In this way, installation becomes an integrated aspect of service, which optimizes every aspect of delivery to our customers. The teams operate all over Europe and also work on all modalities.

Kees Kalkman: Despite the fact that the Aquilion ONE is such an advanced product, its installation and operation are virtually identical to a 64-slice CT scanner. The role of every person who contributes to the installation, operation and end use of the machine has been well considered in design and development not just of the product itself, but also of the supporting services.

VISIONS: *Thank you!*

Dynamic volume CT imaging: workflow and initial experience

P Rogalla[1], J Mews[2], J Hall[2], H Meyer[2], P Hein[1], A Lembcke[1]

The waiting is over: on 9 November 2007, the new dynamic volume CT scanner Aquilion ONE went into operation at the Charité University Medical Center in Berlin, Germany. A heavy-duty mobile crane had to lift the gantry and slowly move it through the window of the new examination room (Fig. 1). Installation, adjustment, calibration and start-up of the system were completed within just seven days. Approval by the local regulatory authorities went smoothly despite the fact that the standard testing procedures for dosimetry had to be adapted to the new technology of the dynamic volume CT unit. It was quickly established, though, that all technical specifications were adhered to and that both low- and high-contrast resolutions not only corresponded with those of the 64-slice CT products but even surpassed them in some areas.

The first patient studied after the unit went into operation presented with non-specific thoracic pain and a CT scan was performed in order to rule out coronary heart disease. Having been on long-term oral medication with beta-blockers she exhibited a resting pulse rate of 76 beats per minute (bpm). With the new CT scanner we were able to study her coronaries without the need for any intravenous (i.v.) medication. Even without previous training on the new system we were able to generate high-quality diagnostic images – due also to the new user interface of the Aquilion ONE. Since it relies on the same functional logic as the previous models, apart from the technical data of the new CT technology, comprehensive training was not considered mandatory.

Study modes

Currently, apart from a 64-slice spiral mode the system offers three different examination modes for computed tomography:

- stitching mode (for whole-body scanning)
- dynamic scanning mode (for dynamic studies and perfusion imaging)

Fig. 1: Lowering the new Aquilion ONE into the examination room (courtesy of L. Krug)

[1]Institute of Radiology
University Medicine Berlin,
Charitéplatz 1
10117 Berlin, Germany

[2]CT Systems Division
Toshiba Medical Systems
Europe BV, Zoetermeer
2718 RP, The Netherlands

- ECG gating (when synchronization with the cardiac action is needed).

Stitching mode

In this mode the CT scanner acquires sequential images based on variable usage of the detector and joins them automatically to provide complete imaging of the whole body. The distance studied is only limited by the maximum length of the examination range (current table length: 2.00 m). Only the very experienced eye will notice that the resulting images were not acquired in a helical scan. Since the time interval between each acquisition is just 1.7 s incomplete breath-holding will only result in minor anatomical changes. Particularly when dealing with critical injection protocols, initial experience has demonstrated that in low volumes differences in vascular contrast may become visible if high flow rates are employed. But it should be noted that these differences in perfusion are also seen in helical CT studies, although not as clearly since the differences in density are blurred continuously over a larger area and do not show abruptly at an interface (Fig. 2). The initial concern that shifting from one position of the table to the next with its concomitant acceleration and deceleration might lead to problems for the patient has turned out to be unfounded. The table accelerates and decelerates so smoothly that to date there have been no complaints even by patients sensitive to motion.

With the new CT scanner planning of the area to be studied is done in the same fashion as with the Aquilion 4- to 64-slice CT models. Once the area to be examined has been defined the optimum subdivision into individual images by variable usage of the detector is computed on the console. This ensures that the examination area selected will neither be too large nor too small. The individual images are joined fully automatically – a process which requires no intervention by the radiologist. Thin as well as thick layers and multiplanar reconstructions can be generated in the same automatic fashion. Moreover, various reconstruction kernels as well as different destinations for the images can be selected (Fig. 3: Screenshot of the user interface).

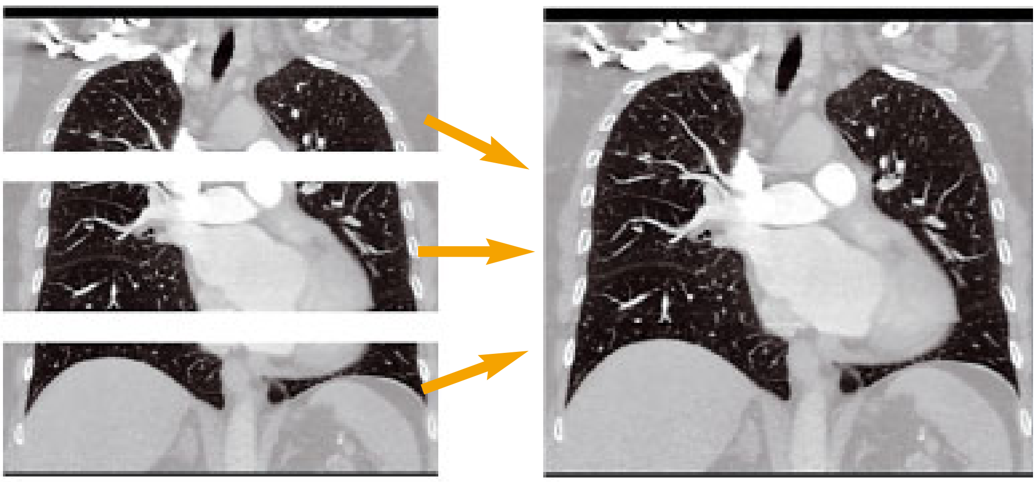


Fig. 2: Example of a thoracic CT study in stitching mode. The final image has been conjoined seamlessly from the three individual images.

Dynamic imaging

This mode of operation is designed for imaging time flow in computed tomography, for example joint movement, perfusion imaging or ventilation of the lungs. Temporal resolution is defined by the sequence of individual images and continuous as well as intermittent acquisition with arbitrary intervals and combinations of these acquisition modes are possible (Fig. 4: Protocol for pancreatic perfusion). Thus, the protocol for a perfusion study of the head may differ from the acquisition protocol of a dynamic series of the pancreas. Typically, abdominal applications require fast data acquisition at the beginning of the arterial perfusion phase, whereas later on in the sequence larger intervals between the acquisitions are acceptable. Image reconstruction can be influenced by priorisation, i.e. later images in the sequence can be viewed first. All images can be sent from the console as a dynamic volume in the new Enhanced DICOM format and are available almost immediately for post-processing.

In order to keep the dose profile in perfusion studies within the normal range of diagnostic CT, each image is generated in low-dose mode; usually, we work with about 80 kV and 50 mAs, resulting in an effective radiation exposure of 0.6 mSv per scan. This allows for imaging of 10-20 sequences without increasing total exposure significantly beyond the scope of a diagnostic CT scan of the same region.

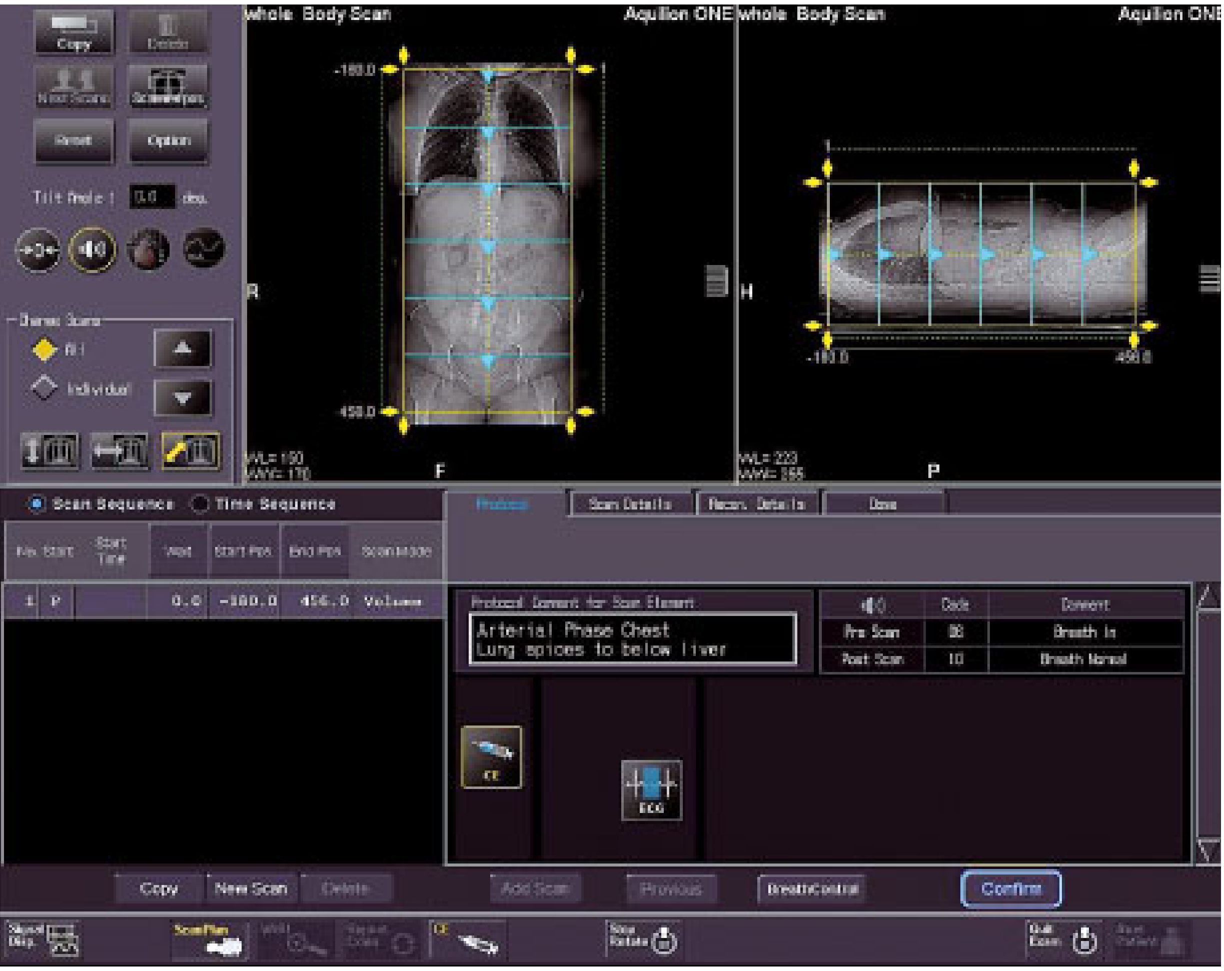


Fig. 3: Screenshot of the user interface during planning of a whole-body scan. Employing a variable proportion of the width of the detector ensures precise delineation of the area to be examined.

ECG gating

This mode of operation is used primarily in cardiac imaging applications. Three basic imaging techniques are possible, with prospective scanning being realized by defining a study time frame within the RR interval. This very effectively reduces radiation exposure. While prospective data acquisition from two heart beats may shorten the effective exposure time, radiation exposure will increase with each image. Continuous acquisition of an entire heartbeat offers the option to reconstruct complete volume data sets retrospectively for any point in time within the RR interval. However, in this case radiation exposure will not be significantly less than with a state-of-the-art 64-slice CT scanner (Fig. 5).

The key breakthrough in cardiac imaging is the increased detector length: 16 cm. Such a detector allows to study the entire heart without having to reposition the table. Overlapping scanning mode as required in 64-slice CTs is no longer necessary. The comparatively high radiation exposure in CT of the heart is almost entirely due to overlapping scanning in helical mode. This so-called overscanning (low-pitch scanning) is needed to ensure that each location will be imaged at each point in time throughout the RR interval. The fact that the Aquilion ONE does not require helical scanning of the heart reduces radiation exposure down to one quarter or one fifth of a comparable study with a 64-slice CT scanner.

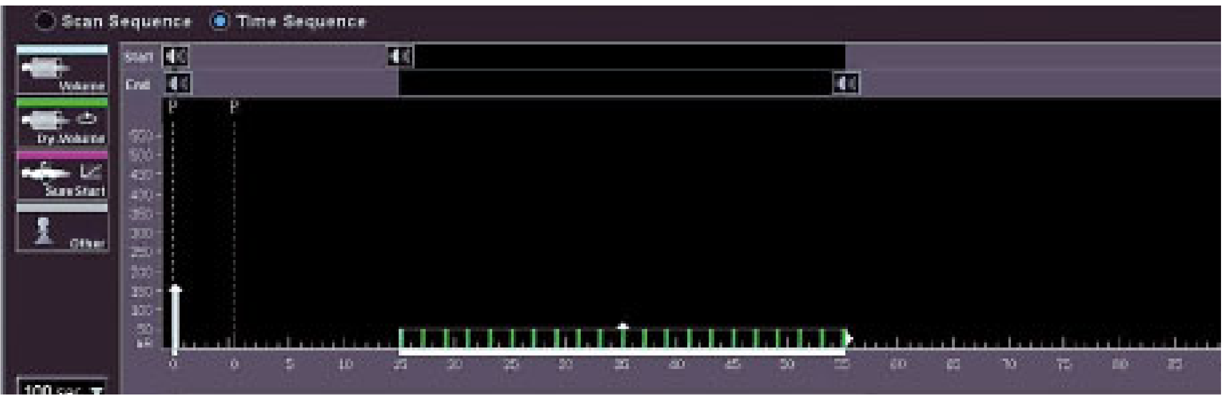


Fig. 4 a: Screenshot of the time sequence; perfusion image protocol with 80 kV and 50 mAs per volumetric scan

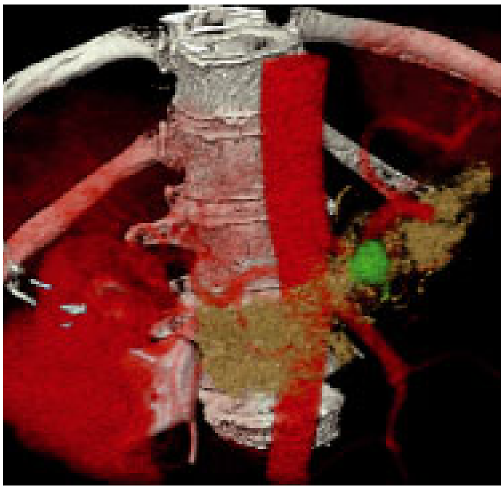


Fig. 4 b: Color depiction of a pancreatic metastasis in renal cancer. The colors reflect true perfusion information.

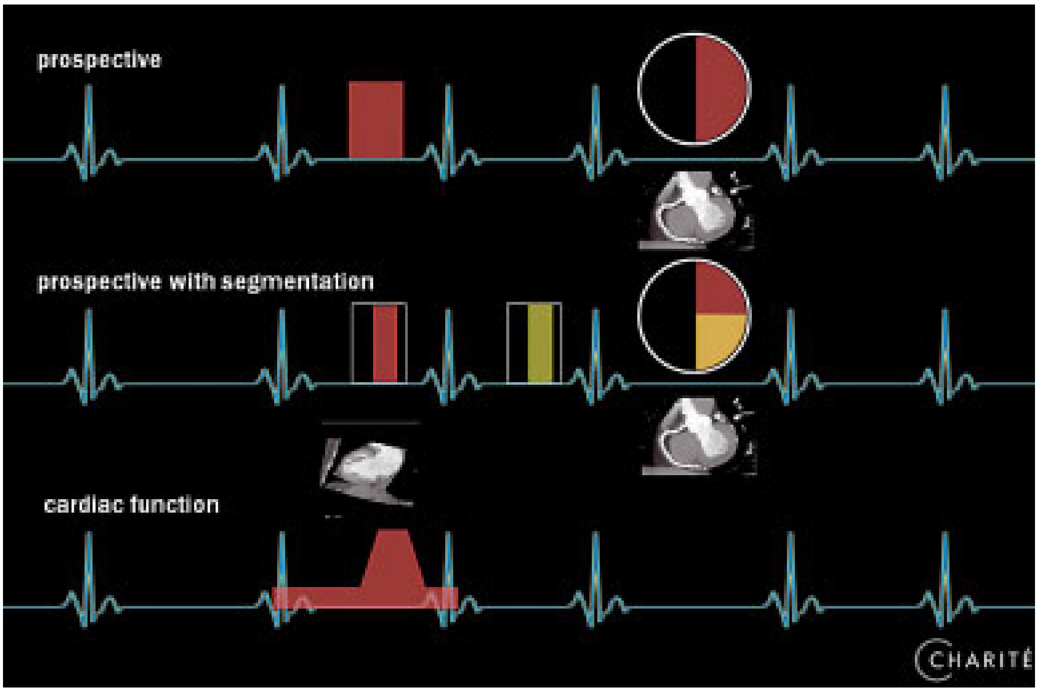
Apart from this dramatic reduction in dose, there is another important aspect: with the first 100 patients we quickly noticed that cardiac arrhythmia – be it absolute arrhythmia or heart rates up to 130 bpm – does not constitute a contraindication for computed tomography of the heart! Online assessment of the imaged RR interval by the software of the new CT unit ensures that image reconstruction can proceed as planned. If the patient experienced an unexpected extrasystole or if there is insufficient data of one image for artefact-free reconstruction, the scanner will automatically image one additional heartbeat in the same fashion and without any noticeable time-delay. The user can set beforehand the maximum number of heartbeats to be considered in image reconstruction, thus extrasystoles have no impact on image quality. Due to the physics involved, helical acquisition cannot offer a similar technique. This is most likely the second dramatic benefit of the new CT modality compared with standard 64-slice computed tomography.

Initial experience with the new system has indicated that now radiation exposure in cardiac imaging is primarily dependent on the temporal resolution to be achieved and therefore on the heart rate of the patient. The shorter the exposure time, the higher the number of segments – and thus heartbeats - to be imaged, which in turn results in a linear increase in radiation exposure. In this context reducing the heart rate does not improve image quality as much as it reduces radiation exposure. Heart rates below 65 bpm do not have to be reduced by beta-blockers, and the radiation exposure of such cardiac studies is about one fifth the dose with a 64-slice CT scanner.

Clinical experience

A surprising aspect of the new CT scanner is the quiet running of the gantry. The CT scanner revolves with hardly any vibration, and the oscillations in the housing often present in older models are hardly noticeable at all. Another improvement is the large LCD monitor built into the gantry. On this screen, the patient can view not only his/her name (ensuring correct identification) but it is also possible to display the ECG or image sequences, e.g. in pediatric studies. Furthermore, the table length of 2.00 m is

Fig. 5: Schematic drawing of the three acquisition modes in ECG gated scanning



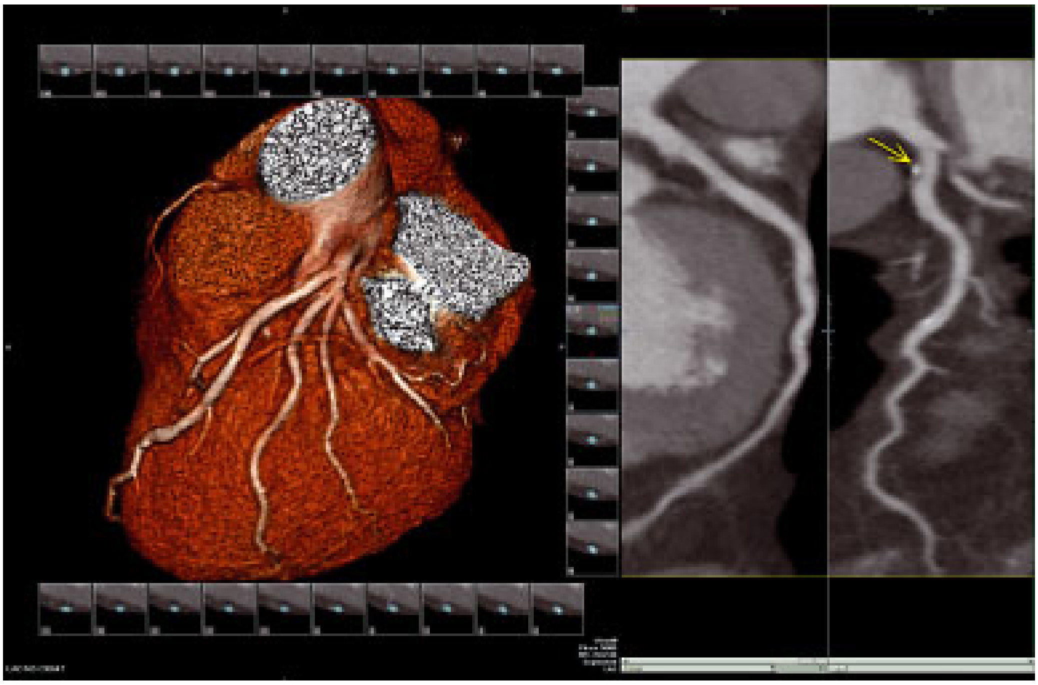


Fig. 6: Cardiac CT demonstrating a soft plaque in the left main coronary artery. With prospective ECG gating, the complete volumetric dataset was acquired during a single heartbeat.

helpful and advantageous not only in Accident & Emergency but particularly so in standard studies. The patient may be positioned in a more flexible fashion and, if needed, the examination can be extended without problem, for example when unplanned studies of the head and neck become necessary in abdominal and pelvic CT studies. In addition, in all examination techniques of the new CT scanner the gantry can be angled which is particularly beneficial in studies of the head: the gantry can be angled that the lenses of the eyes will remain outside the examination area.

We had to get used to the time delay in image reconstruction since, unlike in 16- to 64-slice Aquilion scanners, rapid reconstruction during image acquisition is not possible. The slight delay of a few seconds between image taking and viewing of the reconstructed images, however, impeded neither the clinical workflow nor prompt image assessment.

Simultaneous availability of the reconstructed images on a second console by so-called data base sharing permits assessment right after image reconstruction. The new 4D viewing mode is another exceptional benefit. Perfusion studies can be converted into a dynamic series rapidly and efficiently on the monitor and may be viewed in flexible and interactive fashion. After having checked image quality and finalizing the study, the user decides whether the image data will be sent in standard DICOM or the new Enhanced DICOM format. Any additional DICOM node and any compatible archive can be addressed irrespective of the destinations listed in the study protocol. However, smooth working requires a 1 Gbit/s data link.

Conclusion

Positioning, installation and initial operation of the new Aquilion ONE as well as the initial experience with the first 180 patients has demonstrated that the new dynamic volume CT scanner opens up new vistas in diagnostic computed tomography. Without extensive training on the new system we were immediately able to take advantage of the new techniques for our patients. The initial results surpassed all expectations. Particularly in cardiac imaging the radiation dose can be reduced significantly without any loss in image quality. On the contrary: preliminary comparisons of patients with previous images obtained by 64-slice CTs seem to indicate a slight advantage for the new CT system in terms of image detail and image definition. It is not yet known if perfusion imaging – apart from studies of the head - will be of any clinical significance. The initial results are promising but extensive studies are needed in order to demonstrate any diagnostic advantage. A positive development is the fact that with the new CT scanner perfusion studies can be performed without any dose increase compared to standard helical scanning. This should facilitate perfusion imaging applications significantly. It should also be emphasized that with the new dynamic volume CT there are no limitations to whole-body scanning. Any organ region can be imaged in the usual quality, and the length of the examination area is determined only by the length of the table.

The new CT scanner proves once again that any new technology can only be applied in meaningful fashion if it is embedded in adequate infrastructure. For instance, if the infrastructure of the network is outmoded, the image data cannot be efficiently transferred to the consoles. Once again CT technology has leap-frogged ahead of the IT technology common to this sector. This innovation upsurge becomes even more pronounced if one looks at the new Enhanced DICOM standard: Apart from the Vitrea Workstation (by Vital Images) today hardly any workstation is able to employ this new communications protocol with its benefits of increased transfer rate and transmission of auxiliary data. Here, too, the new CT scanner will set the pace of technological progress in workstations.

J Blobel[1], N Sugihara[1], J Hall[1], J Mews[2], H Kura[1]

Image quality basics of the dynamic volume CT Aquilion ONE

Introduction

In any imaging modality dynamic studies require the interactive acquisition of spatial and temporal data. In the past, the limited axial scan coverage of 20 mm, 32 mm or 40 mm restricted assessment of functional processes. The Aquilion ONE™ is the first CT which can scan the complete volume of an organ within a fraction of a second. With its axial scan coverage of 16 cm at the iso-center of the gantry the brain, heart, pancreas and other organs can now be studied dynamically. This paper discusses the various parameters which impact on the spatial and temporal resolution in dynamic volume computed tomography.

Spatial resolution

CT detectors with optimum spatial resolution require the smallest detector size possible and matching high signal sensitivity. The 320 detector rows, each with 896 detectors, generate a matrix of 286,720 elements with a projected resolution of 0.5 mm x 0.5 mm at the iso-center of the Aquilion ONE. Compared with the 3° cone angle of the Aquilion™ 64, the wider 15° cone angle of the Aquilion ONE requires a new reconstruction algorithm. The new reconstruction algorithm ConeXact™ was developed to overcome cone beam artefacts.

High and low contrast resolution were tested at Charité Berlin (Germany) on the Aquilion ONE installed in October 2007 and compared with the results obtained with the Aquilion 64 in the same hospital. Figure 1 illustrates the phantom test comparison in the axial view. With its phantom diameter of 15 cm the Bead Geometry Module CTP591 (The Phantom Laboratory Inc., USA) comprises a diagonal array of 0.18 mm and 0.28 mm pearls (Figure 1a). Since both types of CT scanner have an identical geometry of 0.5 mm detector elements, in axial MIP reconstructions (Figure 1b and 1c) the pearls are visualized in the same homogeneous fashion. Their difference in size is also demonstrated quite clearly. For the test in Figure 1d the phantom underwent an additional axial offset of 4 cm from the central plane and the gantry was tilted additional 15°. Compared with Figure 1c there was no difference in quality with the isotropic voxels used in image reconstruction. The sagittal views of both CT scanners (Figure 1 e-g) also did not yield any difference in object reproduction. With its reconstruction interval of < 0.5 mm and interpolation between the slices when reconstructing with ConeXact, the Aquilion ONE will also deliver a spatial resolution of < 0.5 mm in the sagittal plane comparable with that of the Aquilion 64. The adequate axial and sagittal images

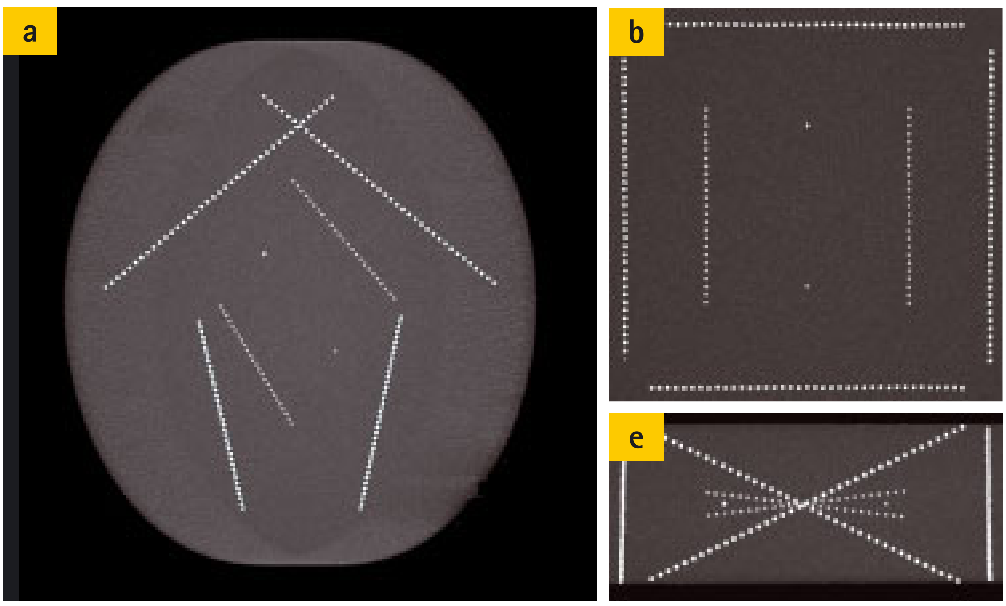


Fig. 1: Phantom test with a) rows of 0.18 mm and 0.28 mm pearls (Aquilion ONE). Axial MIP reconstructions with b) Aquilion 64, c) Aquilion ONE, d) Aquilion ONE, 4 cm off-center position, 15° gantry tilt. Sagittal MIP reconstructions with e) Aquilion 64, f) Aquilion ONE, g) Aquilion ONE with 4 cm off-center position, 15° gantry tilt (Test protocol: 120 kV, 25 mAs, FC 30, MIP)

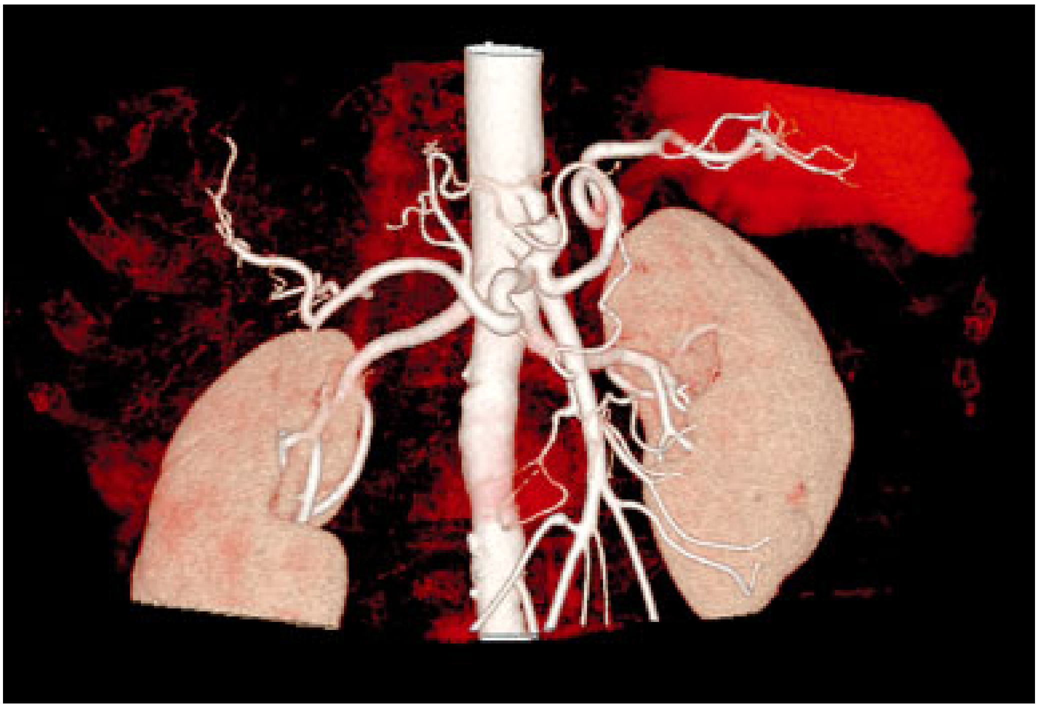
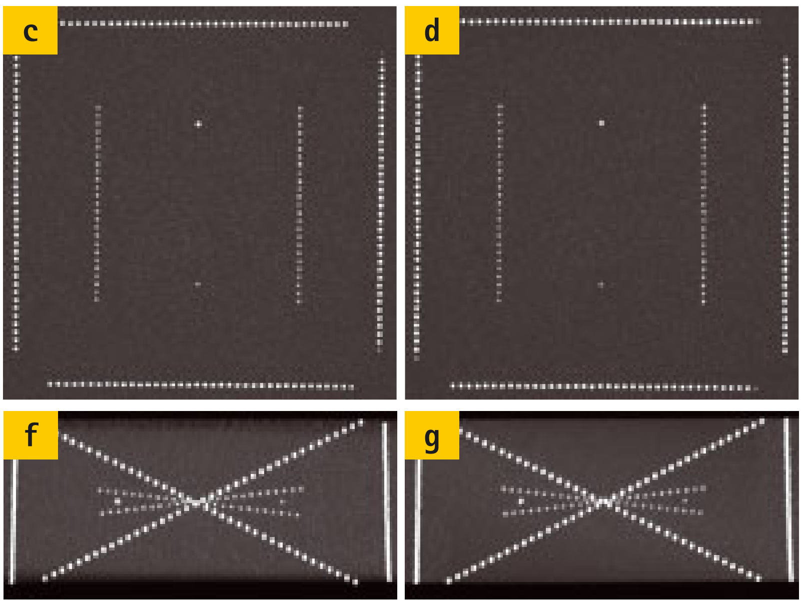


Fig. 2:
3D reconstruction of abdominal angiography with iso-phase contrast agent filling of all vessels (Aquilion ONE). (Courtesy of PD Dr P Rogalla, Charité Berlin, Germany)

of the pearls (Figure 1b-g) demonstrate that in slice reconstruction the ConeXact reconstruction algorithm will maintain spatial resolution even for the gantry tilt. The axial scan field collimation was adjusted with 4 cm for Aquilion ONE and 3.2 cm for Aquilion 64 because of the 4 cm phantom width.

High contrast resolution after the ConeXact reconstruction primarily depends on detector geometry and only to a very small extent on the voxel distance from the central axis in a slice image and the distance of the slice images from the central plane respectively. Since the images of the pearls are equivalent in all axial and sagittal MIP images of Figure 1, this confirms voxel isotropy over the entire scan volume. The clinical example illustrated by the abdominal angiography in Figure 2 shows the high geometric resolution of the contrasted vessels, based on a voxel dimension of < 0.5 mm.

Low contrast resolution was tested with the 2.5 cm wide low contrast module CTP263 (The Phantom Laboratory Inc., USA) combined with the 14.5 cm total wide Catphan® Phantom 412 (16 cm diameter). The axial scan field collimation was adjusted with 14 cm for Aquilion ONE and 3.2 cm for Aquilion 64. The same image reconstruction parameters and low dose protocol with 120 kV and 100 mAs was employed for both CTs. The discernability of circular disks with a diameter of 2-15 mm and at various contrast levels from 0.1% to 1% was comparable in the Aquilion 64 (Figure 3a) and the Aquilion ONE (Figure 3b). This result is yet another indicator that the scan protocols for low contrast applications make low radiation exposure possible with the Aquilion ONE. The example of the coronary CTA in Figure 5 demonstrates the wide range in contrast. In perfusion studies of the brain discrimination between locations differing by just a few HU is also needed because the contrast agent will dissipate in the entire volume of the brain, thus producing rather small differences in HU levels.



Temporal resolution

With the Aquilion ONE the scanning time for volumes up to 16 cm is not determined by the combination of rotation speed and pitch, but solely by rotation speed. Angiography and cardiac studies require fast rotation speeds of 350-600 ms in order to minimize vascular motion artefacts. Perfusion studies call for slower rotation speeds of 750 ms to 1 s because of 30% more projections during the same time for raw data acquisition for image quality improvement. With the volume snapshot of the organs fast rotation speeds are no longer needed in certain studies.

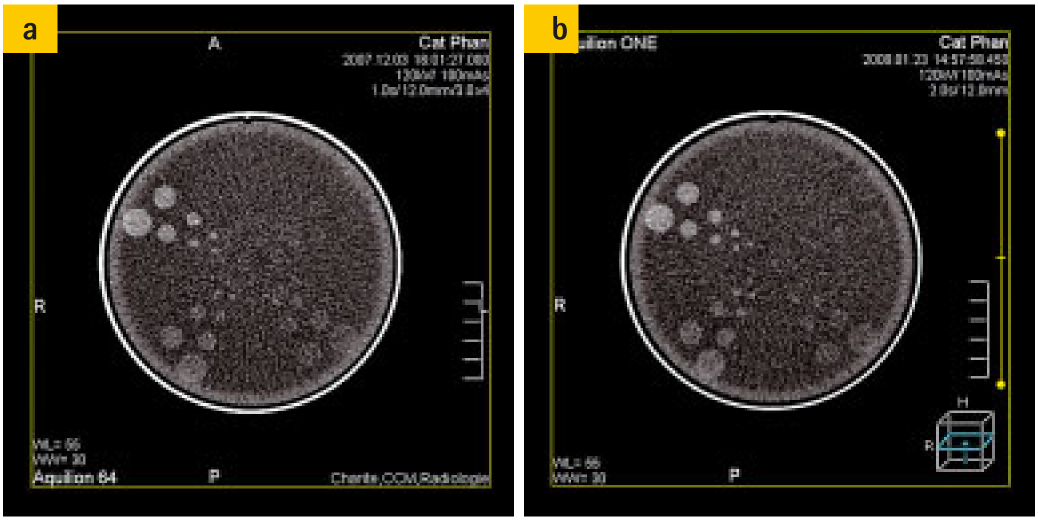


Fig. 3: Low dose phantom test with circular disks of 2-15 mm diameter, each with 0.1%, 0.3%, 0.5% and 1% contrast for a) Aquilion 64 and b) Aquilion ONE. Both CT scanners discern the disks at the various contrast steps on comparable levels. (Test protocol: 120 kV, 100 mAs, FC 43, 12 mm slice)

In CT angiography (CTA), even a rotation time of one second is short enough to "freeze" all vessels within the scan volume. The 1-2 mm wide vessels contrasted in iso-phase maximum will be visualized without any breaks. Diagnostic studies of very small vessels, e.g. the coronaries, are hampered if the concentration of the contrast agent at the end of the bolus transit time is too low and if helical MSCT is employed.

Half reconstruction or multi-segment reconstruction can be applied for coronary artery studies. With the Aquilion 64 in helical mode rotation speed and pitch are matched to the prognostic heart rate of the patient. For optimum temporal resolution a certain number of data segments will be employed, depending on the heart rate. In the Aquilion ONE the rotation speed of 350 ms, 375 ms or 400 ms will also be matched to the heart rate and number of segments, but without the pitch and its side effects. For a heart rate of 60 bpm, i.e. an R-R interval of 1,000 ms, a 350 ms rotation will expose 35% of all R-R phases. The time interval of the 350 ms exposure time will be gated by the R-signal to the adjustable cardiac phase range. With increasing heart rate two, three, four or five data segments from several consecutive beats will be used for multi-segment reconstruction (Figure 4). Minimum temporal resolution will improve proportionally to

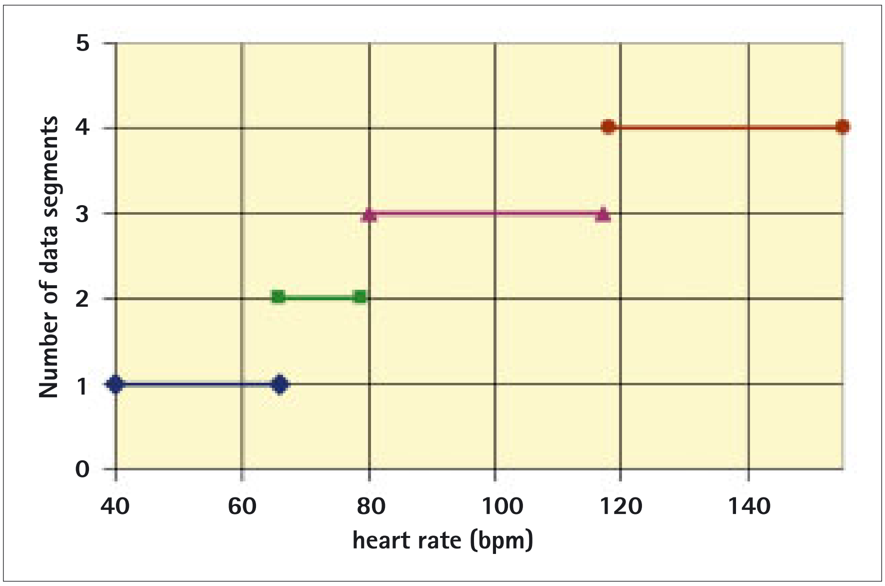


Fig. 4: Number of data segments in multi-segment reconstruction for Aquilion ONE, depending on the heart rate

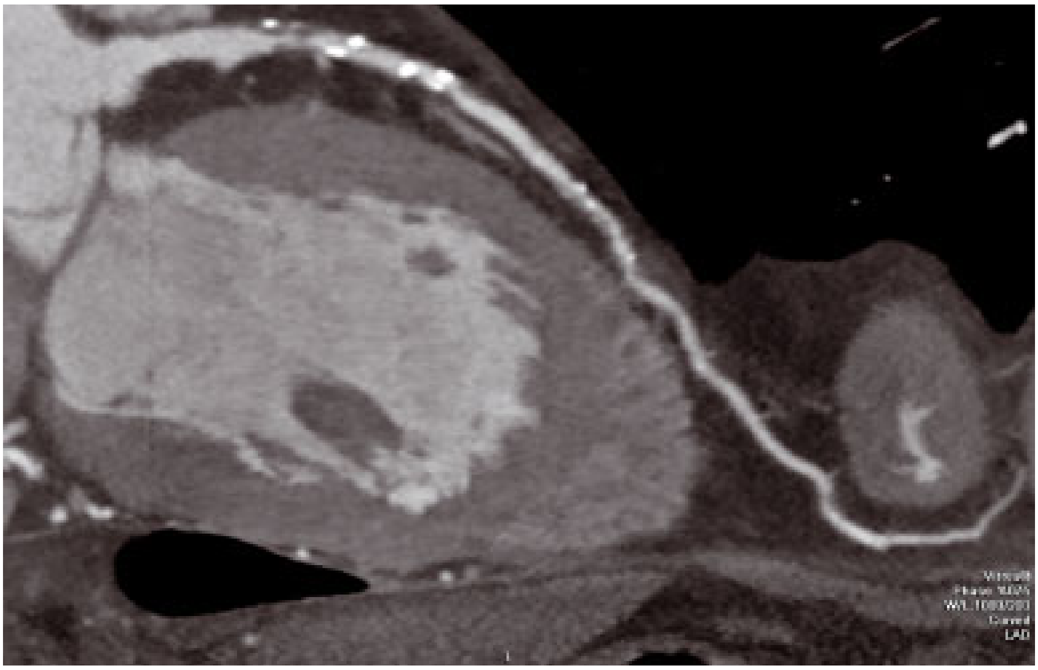


Fig. 5: Curved reconstruction of an LAD coronary artery (Aquilion ONE). Size as well as HU density of the plaque composition can be assessed even in low contrast levels. (Courtesy of Dr A Lembcke, Charité Berlin, Germany)

87 ms, 58 ms, 44 ms and 35 ms respectively and will match the faster motion of the heart. Here each data segment will be adjusted to an identical cardiac phase in order to generate correct vascular superposition of the consecutive cardiac cycles. Radiation exposure increases with the number of segments and the number of rotations. On the other hand compared with a heart rate of 50 bpm, due to the shorter R-R interval the pulsed exposure time per one cardiac cycle at 100 bpm will be reduced for the same cardiac phase percentage, thereby reducing exposure.

Cardiac action already undergoes real-time monitoring during the scanning interval. In case of arrhythmia, extrasystole or excessive changes in heart rate the tube is turned off and the cycle restarts with the next R-gating signal. The user monitors, corrects or deletes the reconstruction time ranges in each R-R cardiac cycle with the ECG Editor to avoid any loss in image quality due to cardiac dysrhythmias. In extreme case only one "normal" R-R cycle can be retrospective selected for the half reconstruction.

Any discussion of data consistency from several R-R cycles in multi-segment reconstruction should take into account the fact that in helical scanning or step and shot mode 10-15 cardiac cycles (depending on the heart rate) will affect the image. Since the curved reformatted vessels are computed based on the cardiac cycles, the Aquilion ONE not only offers the benefit of a heart rate adapted temporal resolution of 35-175 ms (for 1-5 segments) but also that just a small number of cardiac actions is needed for the complete set of 3D data. Partial volume artefacts and step artefacts after helical or "step and shoot" scanning are precluded. Curved MPR reconstruction of the LAD artery from just one heartbeat of the patient at a heart rate of 58 bpm and with a temporal resolution of 175 ms will yield a representative result (Figure 5).

Summary

The spatial image voxels and the data acquisition time are image quality elements of dynamic volume CT. Even when looking at dose equivalency, high and low contrast resolution of the Aquilion ONE, the first dynamic volume CT scanner, compare favorably with the results of the Aquilion 64. The volume snapshot within less than 200 ms of a whole organ allows functional studies. Overbeaming is reduced proportional to the larger axial width of the detectors. Unnecessary overranging is avoided by selective choice of the axial scan width. After the scout scan the number of detector rows is adjusted between 80 to 320, depending on the measured size of the organ. Overscanning of the region scanned due to scan stop delay is possible only in helical mode but is ruled out in dynamic volume scan mode. Compared with the helical scan of a 64 MSCT and its standard pitch of 0.2 for cardiac scanning, the lack of oversampling in dynamic volume CT reduces radiation exposure by 80%. This example demonstrates the ability of the Aquilion ONE to employ this dose reserve in cardiac and perfusion studies. The dimension of a temporal resolution of > 35 ms and a spatial voxel resolution < 0.5 mm open up new horizons for 4D accuracy in diagnostic radiology, including the diagnostic study of very small changes in tissue density.

[1] *CT Systems Division*
Toshiba Medical Systems Corporation
Tokyo 113-8456, Japan

[2] *Department of Radiology, Charité*
University Medicine Berlin, Campus
Charité Center, 10117 Berlin, Germany

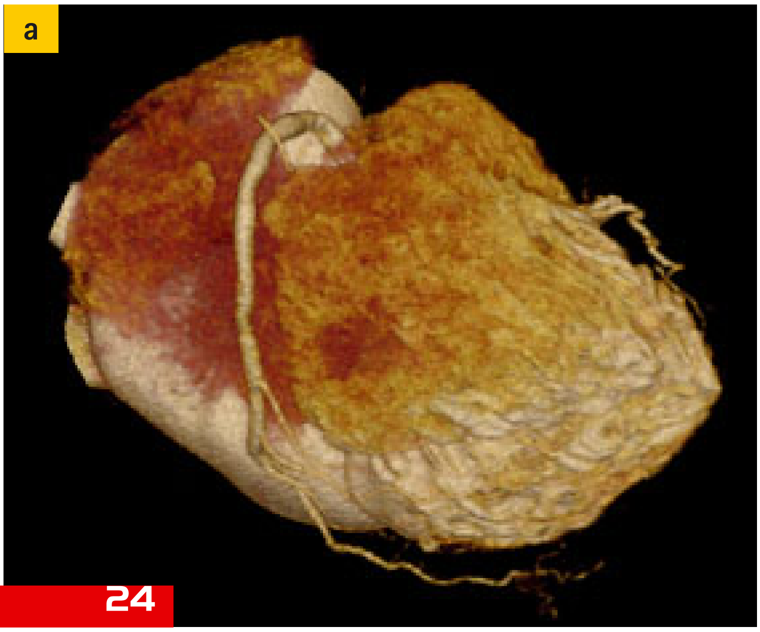
Cardiac Imaging with the 320 Detector Row CT

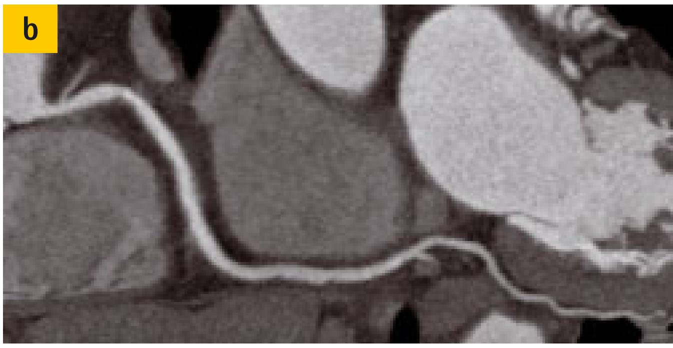
A Lembcke[1], P A Hein[1], J Mews[1], J Blobel[2], P Rogalla[1]

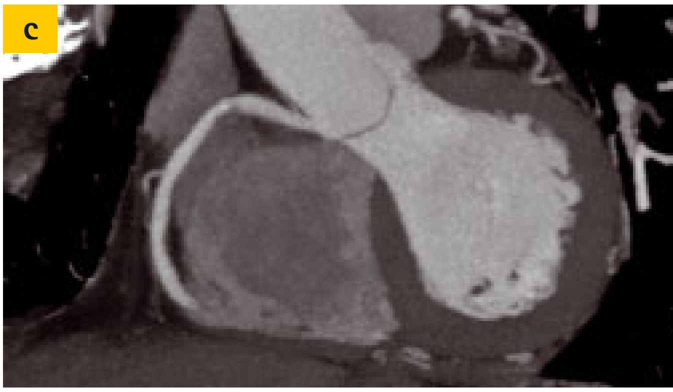
[1] Department of Radiology, Charité University Medicine Berlin, Campus Charité Center 10117 Berlin, Germany

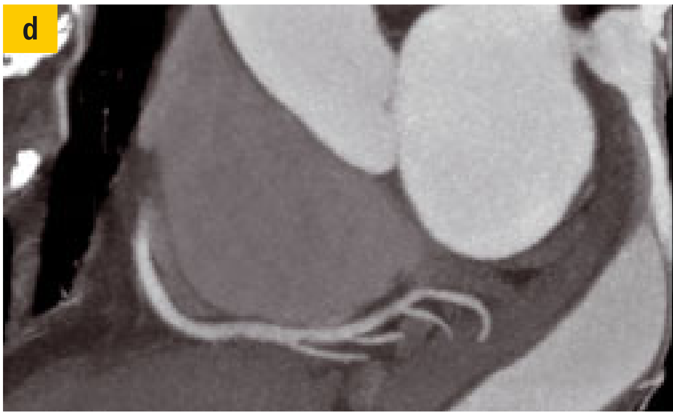
[2]Toshiba Medical Systems Hellersbergstraße 4 41460 Neuss Germany

The advent of multislice computed tomography (MSCT), initially with four rows of detectors, and its widespread introduction into clinical practice barely eight years ago provided new opportunities in non-invasive cross-sectional cardiac imaging, particularly in diagnostic studies of the coronary arteries. Numerous studies demonstrated the potential inherent in MSCT in diagnostic investigations of coronary artery disease, in particular for patients with low pre-test probability of disease, low heart rate, and low calcium score. The principal benefits of multislice helical scanning are primarily due to improved spatial and temporal resolution combined with ECG gating of the acquired data. Continuing development of scanner technology resulted in thinner collimation with slice thickness in the sub-millimeter range as well as faster rotation speed. This in turn led to steady improvement in spatial and temporal resolution while the thicker detectors ensured larger volume coverage. However, in a 64-slice MSCT scanner the 32 mm wide detector (64 x 0.5 mm) cannot cover the entire heart. Thus, complete coverage requires continuous movement of the table

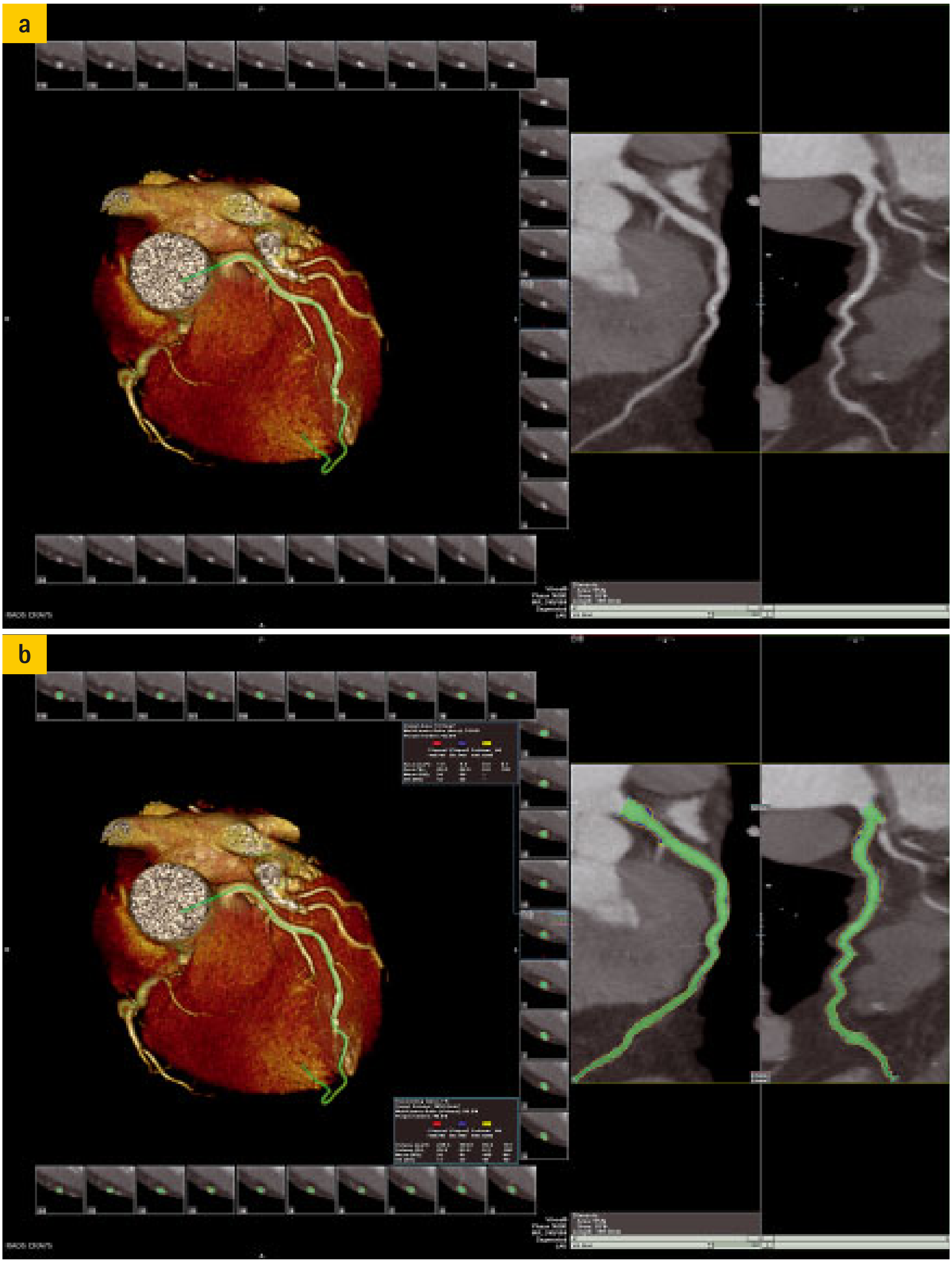








Case 1 *Fig. 1a-d:*
Normal right coronary artery in 3D, MPR and MIP

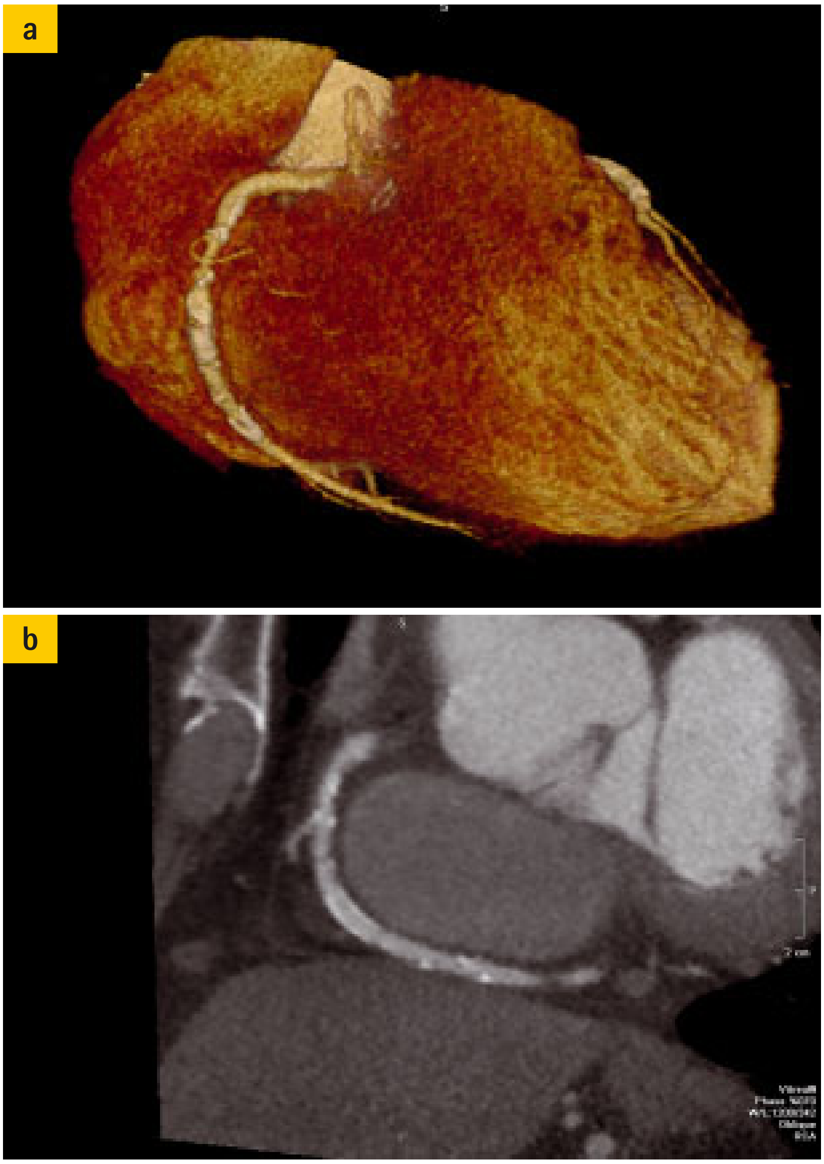


Case 2 *Fig. 2a-b: Minute atheromatous wall degeneration of RIVA in 3D, MPR, including soft plaque visualisation with SurePlaque*

which is realized either by 1) helical scanning with continuous table feed – a mode primarily employed in coronary contrast CT angiography with retrospective ECG gating, or by 2) incremental scanning with discontinuous table feed – a mode primarily employed in coronary calcium scoring with prospective ECG gating. Depending on the scanning mode selected, there will be various limitations. Helical scanning with retrospective ECG gating allows for image reconstruction at any point in time within the R-R interval and improves effective temporal resolution by multi-segment reconstruction. However, since high data density is mandatory (i.e. high degree of oversampling with multiple overlap of the slices) a low pitch (usually about 0.2) is required. Images with multiple overlap and continuous exposure over the entire cardiac cycle

Case 3

Fig. 3a-b: RCA with medium stenosis (medial) and implanted stent (distal)



cause the major drawback of this acquisition mode: significant radiation exposure. Therefore, it was suggested to replace overlapping helical acquisition with continuous exposure by non-overlapping incrementation with selective exposure within the cardiac cycle.

However, incremental scanning with prospective ECG gating does not allow multisegment reconstruction which is often highly desirable in higher heart rates. In addition, various partial volume data sets have to be "concatenated" and fused into a single volume data set. In low heart rates with regular rhythm this will yield acceptable image quality, in higher heart rates and arrhythmias, however, artefacts are to be expected, resulting in blurred or stepped vascular contours due to differences in the magnitude and speed of the coronary artery deflection.

These problems have been solved by 320-slice computed tomography. The planar detector fitted with 320 rows of 0.5 mm detectors and a coverage of 16 cm along the z-axis of the patient allows for the acquisition of a high resolution data set of the entire heart in a single rotation. The benefits of this technology are obvious: by covering the entire organ a complete volume data set of the heart can be acquired in one heartbeat and without repositioning of the table. Thus, the limitations of helical and incremental scanning, i.e. the fusion of potentially incongruent raw data originating from different cardiac cycles, are overcome. This helps to avoid artefacts in the reconstructed images, particularly those obtained in patients with arrhythmias. Unlike helical scanning, 320-slice CT scanning acquires data without overlap - a key precondition for reducing radiation exposure. In patients with a low heart rate and stable cardiac rhythm, it is thus possible to acquire data in one heartbeat by selective exposure within the cardiac cycle (usually 70-80% of the R-R interval); in ideal circumstances this means an effective dose of about 3 mSv. Scanning is performed with prospective ECG gating. It should be emphasized that even under the most unfavorable conditions the very low radiation exposure permits repeat scans – although the resulting effective dose is doubled, its value of 6 mSv is still below the current standard dose in a CT study of the heart. It should also be noted that even with prospective ECG gating in 320-slice mode the data can be acquired across several cardiac cycles, thus permitting image computation with the multisegment reconstruction algorithm. The latter increases temporal resolution in order to avoid motion artefacts in higher heart rates and is thus a further essential improvement over the 64-slice CT scanner. Nevertheless, it has to be emphasized that data acquisition across several cardiac cycles for the purpose of multisegment reconstruction will increase the effective dose.

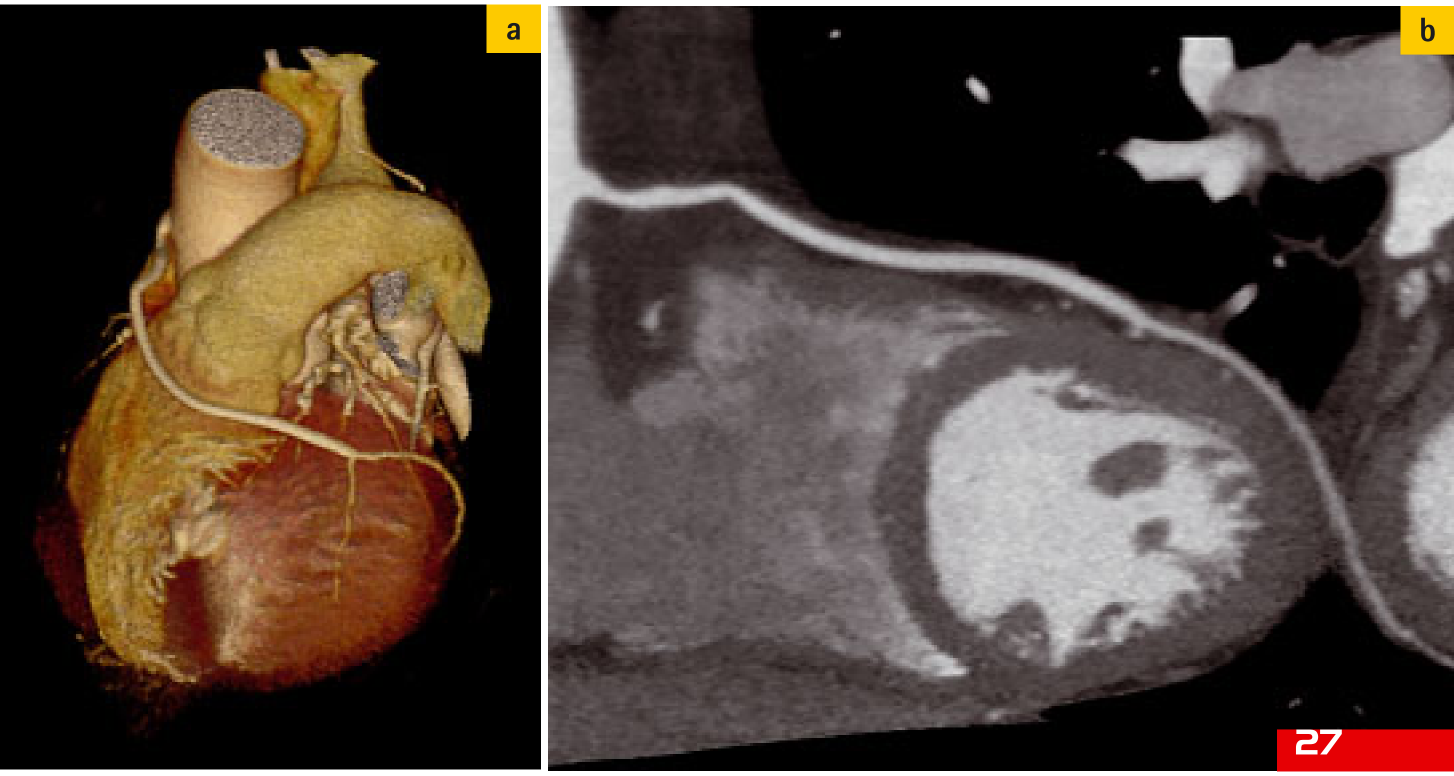
The short acquisition time of the raw data – which may be in the second to sub-second range – also reduces significantly the required amount of intravascular contrast agent. In patients with normal cardiac function and visually monitored bolus tracking (the scan is manually started as soon as the contrast agent becomes visible as it enters the left heart), a volume of 50 ml of contrast agent and a flow rate of 5 ml/sec will almost always result in good contrast of the left cardiac cavities, aorta and coronary arteries.

Our initial experience with more than 100 patients indicates that the Aquilion ONE generates outstanding image quality (Figures 1-4). In all the patients we studied the information gained from the data acquired contributed to further clinical decision making – the failure rate (the number of non-diagnostic scans) tended toward zero.

A further, altogether new area of application in non-invasive diagnostic cardiac imaging is myocardial perfusion imaging by computed tomography. In dynamic scanning mode the CT scanner is able to record the volume data of the entire heart, either continuously during a specific interval or intermittently in certain time intervals. Future studies will have to investigate the accuracy of this mode in demonstrating myocardial perfusion disorders, its relevance in clinical routine and in particular its significance compared to competing imaging modalities.

Alexander Lembcke MD
Department of Radiology
Charité, University Medicine Berlin,
Campus Charité Center
Charitéplatz 1, 10117 Berlin, Germany

Case 4 *Fig. 4a-b: Patient with a sequential venous bypass (3D and MPR)*



R Irwan
H B K de Vries

A brief summary of patient doses of dynamic volume CT

Dynamic volume CT imaging or 4D CT imaging has attracted much attention recently. The world's first dynamic volume CT scanner with 320 detector rows covering a scan length of 16 cm has just been introduced by Toshiba as Aquilion ONE™ (see article "The History of CT" in this issue). This wide coverage enables scanning of the heart or brain within one rotation, eliminating the need for helical scanning.

The aim of this paper is to clarify advantages of cardiac applications with "one-beat whole heart imaging" in clinical cases. Particularly, the dose issues in several main cardiac applications will be presented.

Case 1

A 62-year-old male patient with a family history was admitted to the hospital with symptoms of suspected Coronary Artery Disease (CAD). The patient was referred to an examination for calcium scoring, in the first case. The patient was scanned on Aquilion ONE™ scanner using an examination protocol shown in Table 1. The patient had a heart rate of 75 beats per minute (bpm) during the CT scan.

Table 1: Examination protocol for cardiac calcium scoring.

Scanner	Aquilion ONE
Scan area	Heart
Scan length	120 mm
Rotation time	0.35 s
Heart rate	75 bpm
kV	120
mA	300
Temporal resolution	175 ms
Spatial resolution	0.35 mm
Patient dose	2 mSv

Fig. 1: Aquilion ONE™ calcium scoring allows detailed examination of coronary calcium and plaques. Color coding in all views combined with volume measurements facilitates a quick and accurate assessment of atherosclerotic lesions.

Roy Irwan, PhD, Henk B K de Vries, Toshiba Medical Systems Europe BV, Zilverstraat 1, 2718 RP Zoetermeer, The Netherlands

Case 2

A 55-year-old female patient with a history of hypertension was admitted to the hospital with symptoms of suspected coronary artery stenosis. The patient was scanned on Aquilion ONE™ scanner using an examination protocol shown in Table 2. The patient had a heart rate of 86 bpm during the CT scan. Multi segmental SUREProspective Cardio reconstruction has been used in which three segments were needed to match the patient's heart rate.

Table 2: Examination protocol for coronary angiography using multisegmental SUREProspective Cardio.

Scanner	Aquilion ONE
Scan area	Heart
Scan length	120 mm
Rotation time	0.35 s
Heart rate	86 bpm
kV	120
mA	400
Number of segments	3
Temporal resolution	58 ms
Spatial resolution	0.35 mm
Patient dose	8 mSv

Patient doses for cardiac applications

Patient dose depends strongly on the type image acquisition. In turn, the type of image acquisition would depend on the clinical requests by a medical doctor. For example, CT coronary angiography requires excellent spatial and temporal resolution whereas the assessment of the anatomy of pulmonary veins and the left atrium has sufficient with a modest setting. Generally, the higher the requirements for image quality, the longer scan time and the higher patient dose.

Effective patient dose, expressed in mSv, can be derived from the CT dose index (CTDI), expressed in mGy, and dose-length product (DLP) expressed in mGy.cm. Patient dose from cardiac CT coronary angiography is relatively high, mainly due to the need to acquire the heart more than one cycle. However, using ECG triggered dose modulation the dose can be reduced down to approximately 3 mSv. In contrast, patient dose from acquisitions for calcium scoring purposes may be as low as 2 mSv.

We report two cases representing calcium scoring and coronary angiography examinations.

Figure 1 shows Toshiba Calcium Scoring graphical user interface that enables a fast and accurate definition of a patient's calcium burden. Both Agatson and volume scoring are available to assure the most accurate assessment.

A volume rendering of the coronary datasets is shown in Fig. 2a which allows you to determine the severity of a suspicious coronary artery at a glance.

The accurate segmentation tool automatically segments the complete coronary tree allowing the precise examination of all coronaries down to the most distal segments (Fig. 2b).

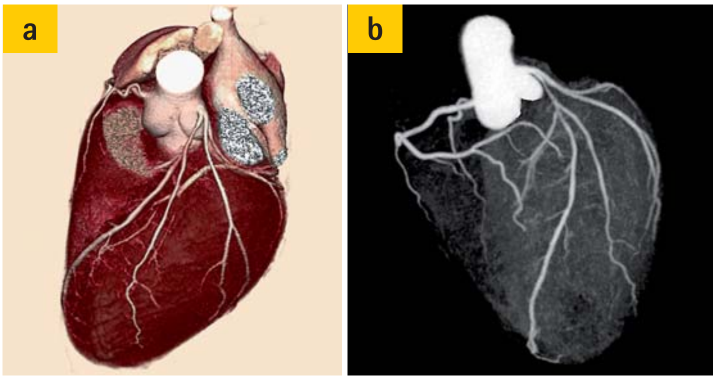


Fig. 2a: Volume rendering of the coronary CTA datasets providing very accurate visualization of coronary arteries.
Fig. 2b: Segmentation of the complete coronary tree allowing the precise examination of all coronaries.
Courtesy of Dr. K. Katada, Fujita Health University, Aichi, Japan

Summary

In this paper, the technical requirements of cardiac dynamic volume CT imaging and some main clinical applications have been presented. CT-angiography of the vascular system is one of the most frequently employed examinations in CT. Contrast-enhanced scanning of the cardiac cavities and coronary arteries is now possible with one single rotation.

Patient dose should always be related to the need of image acquisition and image quality. Typical acquisition and reconstruction parameters for some clinically established cardiac CT applications are summarized in Table 3. With Aquilion ONE™ and using three segment reconstruction, we can achieve a temporal resolution of 58 ms. This combination of low-dose and better temporal resolution drastically improves diagnostic quality and patient safety of CT.

Examination	Synchro-nization	Rotation time (s)	Tube voltage (kV)	Tube current (mA)	Scan coverage (mm)	Scan time (s)	Dose modulation	Patient dose (mSv)
Calcium scoring	Prospective triggering	0.35	120	300	120	0.35	Pulsed	2
CTA coronary arteries	Retrospective gating	0.35	120	400	120	0.35	Pulsed	2.8
LV function	Retrospective gating	0.35	120	400	120	1.4	Modulated	5

Table 3: Typical acquisition and reconstruction characteristics of 60 bpm cardiac CT examinations on Aquilion ONE™.

Initial Experiences with the 320 Detector Row CT in Neuroimaging

E Siebert

Fig. 1: Toshiba Aquilion ONE, 320-detector row CT installed at the radiology department at Charité University Hospital. Neuroradiology CT group (left: the author, right: G Bohner, MD).

Since November 2007 our department has been equipped with the latest Toshiba dynamic volume computed tomography scanner featuring 320 detector rows – the Aquilion ONE. It is the third clinical dynamic volume CT scanner worldwide and the first in Europe. The increased detector width of 16 cm, unique in CT technology so far, enables simultaneous imaging of large volumes. Thus, during one single rotation structural imaging data of the whole-brain can be acquired. But not only morphological information can be gathered quickly. The main advantage of this new-generation CT scanner is the possibility to acquire physiological information of the whole-brain. Continuous scanning enables dynamic time-resolved imaging of the intracranial vasculature (4D-CT angiography/4D-CTA) and CT brain perfusion (CTP). These options are likely to have a considerable impact on computed tomography neuroimaging since some severe limitations of conventional multislice CT imaging have been overcome. Due to the limitation of conventional detector widths to 32 mm (64 detector rows x 0.5 mm) whole-brain coverage cannot be achieved, a fact that reduces CT perfusion to partial brain coverage and renders 4D-whole-brain CTA impossible. Below, some information about the protocols used in our department at Charité University Hospital, Berlin, will be provided and some of our experiences with this long anticipated and exciting new CT technology will be illustrated.

We use single rotation volume acquisition techniques for unenhanced and post-contrast cranial CT scans as well as for cervicocranial CT angiography (3D-CTA). In contrast to conventional spiral mode multislice scanners, cervicocranial CTA coverage is performed incrementally. Usually three steps are required to cover the volume between aortic arch and the vertex. Bolus timing can be calculated with a test bolus or performed manually by a low-dose dynamic (SUREStart) scan at the level of C4.

For the dynamic, time-resolved imaging methods, 4D-CTA, CTP and a combination of both (4D-CTA/CTP) protocols with both intermittent and continuous scan components are used. Below, the combined protocol will be addressed briefly.

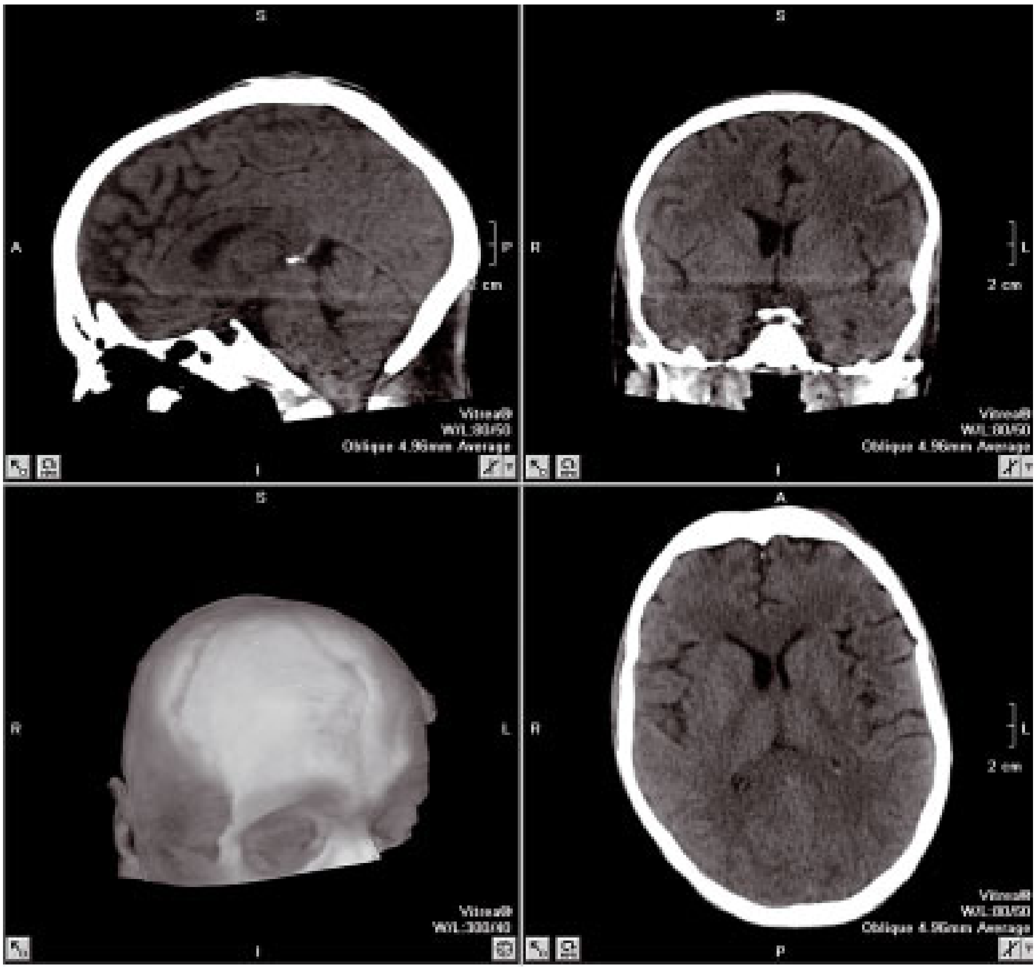
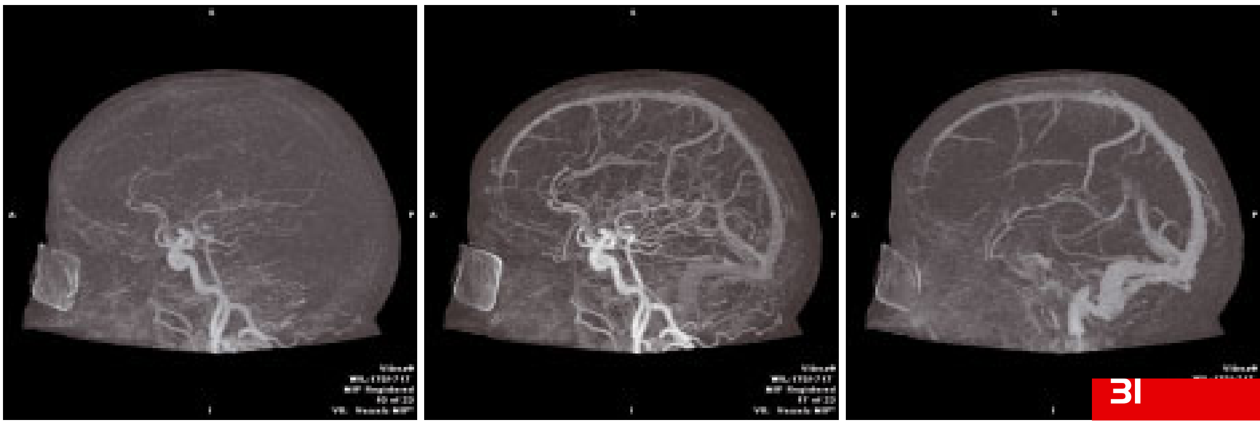


Fig. 2: Unenhanced, single-rotation, volume cranial CT consisting of 320 x 0.5 mm axial sections. This allows for high-quality multiplanar reformation.

For the 4D-CTA/CTP protocol, following test bolus-assisted calculation of circulation time, a 50 second total duration protocol of combined intermittent and continuous scanning is used. Continuous scanning is performed to gather the complete 4D-CTA information during the first pass of the contrast media bolus as well as the essential information for the whole-brain CTP. Intermittent scans before the continuous scan block are used to construct a mask for bone-subtraction which is indispensable for adequate 4D-CTA post-processing. Intermittent scans after the continuous scan block add information to the CTP as with conventional scanners. The bolus of iodinated contrast agent amounts to 50 ml.

Dynamic scanning is performed using an 80 kV and 100 mAs protocol to keep radiation exposure at a level comparable with conventional CTP investigations. The resulting dose-length product is 2355,4 mGy*cm. Multiplied with the ICRP-factor (k = 0.0023 mSv/(mGy*cm) for the head) this should result in a calculated effective dose of 5,4 mSv which is in line with Toshiba's phantom measurements where radiation exposure for the dynamic whole-brain 4D-CTA/CTP combination was 6.4 mSv.

Fig. 3: Physiological sequelae of intracranial 4D-CTA images from early arterial via arterio-venous to venous phase of contrast passage. Sagittal, bone-subtracted 4D-CTA whole-brain MIPs.



According to our clinical experiences motion artefacts are substantially reduced when using the volume CT mode and 3D-CTA protocols. This applies especially to uncooperative patients, who are a considerable group within the emergency patient population, and represents a significant advantage over conventional incremental acquisition (CCT) and spiral acquisition of cervico-cranial 3D-CTA.

The CCT results in a single volume of 320 x 0.5 mm axial slices that can be reformatted as required (Fig. 2). So far, dynamic volume CT has mainly been performed for vascular trauma, acute stroke, chronic cervico-cranial vascular insufficiency as well as veno-occlusive disease. Figure 3 illustrates the quality of information gathered by such a 4D-CTA protocol. As even these few examples show, this new 320-detector row CT scanner generation virtually opens up the fourth dimension for neuroradiological evaluation of the brain. The preliminary evaluation of shunting vascular disorders has already been performed successfully.

Figure 4 illustrates an arterio-venous malformation within the basal ganglia which is fed by enlarged lenticulostriate branches of the middle cerebral artery. CT-based neuroimaging was performed due to persistent headaches of the patient. The aneurysmatic nidus is well shown as is the deep venous drainage of the AVM. Both findings provide important information to assess the probability of intracranial hemorrhage and therapeutic procedures. A novel feature of this new scanner generation is the possibility to assess acceleration of cerebral circulation time due to arterio-venous shunting. Already in the arterial phase early venous drainage via the internal cerebral vein and the straight sinus is evident whereas other venous structures, e.g. the superior sagittal sinus, are not yet opacified. This broadens the diagnostic spectrum of CT-guided diagnosis substantially and is most likely beneficial for evaluation of diseases with altered hemodynamics. Dynamic whole-brain CT imaging does not only allow assessment of circulation time changes in shunting vascular disorders and venous arterialisation, but also delay of venous outflow in the setting of veno-occlusive disease, especially in cortical vein thrombosis, a subtle diagnosis previously confined to invasive catheter angiography. All these neuroradiologically important issues can now be addressed directly and dynamically by whole-brain 4D-CTA.

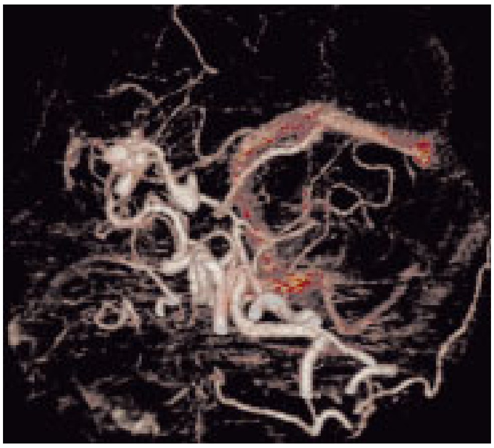
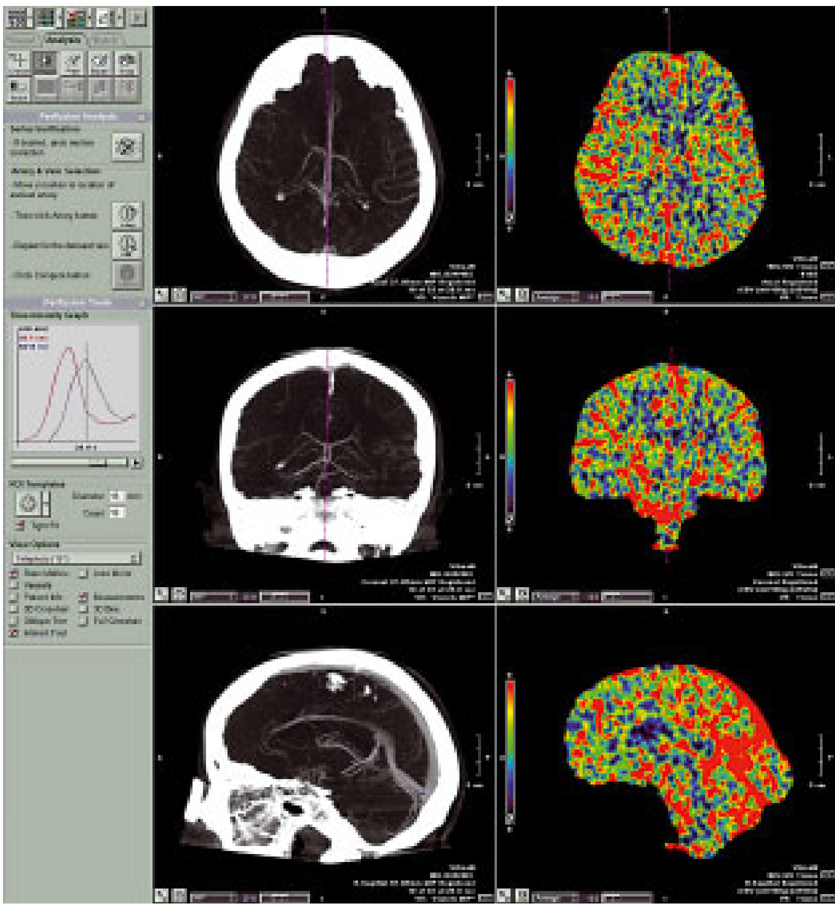


Fig. 4: Arterio-venous malformation within the basal ganglia fed by lenticulostriate branches of the middle cerebral artery. Note the highly irregular and lobulated appearance of the aneurysmatic nidus. The mid-arterial image shows venous opacification of the internal cerebral vein and the straight sinus. Other venous structures, such as the superior sagittal sinus, are not yet visible.



Comprehensive neuroimaging of cerebrovascular insufficiency and namely imaging-guided diagnosis of acute stroke will most probably benefit from the dynamic whole-brain imaging functionalities provided by 320-detector row CT. The sensitivity of CT perfusion will almost certainly increase, especially when lesions in infratentorial or higher fronto-parietal locations are the cause of the neurological deficits. Whether this new quality of information will be of clinical importance, however, remains to be determined. As illustrated in Figure 5, the parameter maps of CT perfusion profit greatly from the high spatial resolution, not only in the axial plane but also in the z-direction. The voxel size of 0.5 mm along the z-axis by itself is an important new feature and particularly meaningful since until recently it was impossible to reap the benefits of such through-plane resolution for the whole-brain from the cerebellar tonsils to the motor and somatosensory cortex. This near-isotropic data allows for elaborate post-processing with all its potentials and options the radiologist is used to from multislice CTA (Fig. 6).

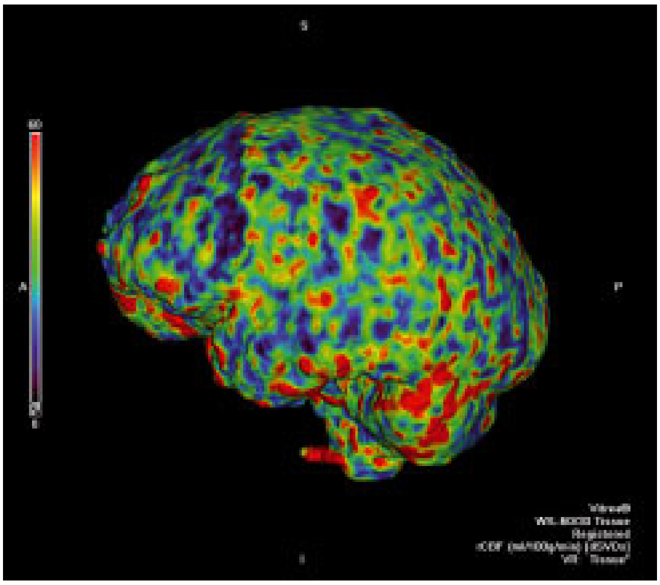


Fig. 6: Surface rendered image of a physiological cerebral blood flow (CBF) map to illustrate one of the various novel options of CTP data post-processing

However, the quantity of data this new CT scanner generation has to gather in order to be able to provide the new quality and dimension of information increases substantially. Comprehensive neuroimaging, including unenhanced CT, 4D-CTA/CTP and cervico-cranial 3D-CTA, amounts to approx. 10,000 DICOM images that have to be processed and stored within a reasonable time for the new technology to be useful in clinical routine. That means the new 320-detector row scanner has high infrastructre requirements in terms of network connections and PACS.

In short, 320-detector row CT opens up the fourth dimension for comprehensive neuroimaging of the whole-brain. Isotropic, dynamic whole-brain data acquisition allows for unsurpassed and unprecedented quality of post-processing, resulting in simultaneously acquired high-class 4D-images of the intracranial vasculature and perfusion maps covering the whole-brain. The new quality of information, however, requires increased data quantities, a fact which poses a challenge to network and PACS infrastructure. Dynamic whole-brain imaging by 320-detector row CT is an exciting and very promising method for comprehensive neuroradiolo-gical assessment of cerebro-vascular diseases although its clinical value for specific disease entities still needs to be determined in further studies.

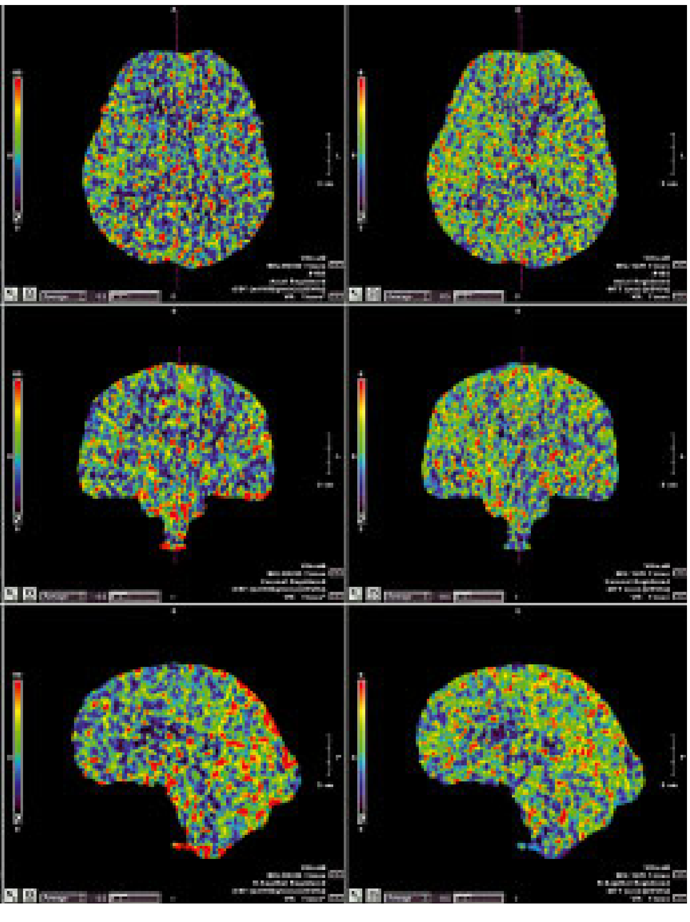


Fig. 5: Generation of CT perfusion maps with the Vitrea 4.0 software (Vital Images, Minnesota, USA). The resolution of 0.5 mm along the z-axis allows for multiplanar reformation of the whole-brain perfusion maps without loss of information.

Eberhard Siebert
Department of Neuroradiology
Charité – University Medicine Berlin
Charitéplatz 1
10117 Berlin
Germany

Fresh Blood Imaging and Time-SLIP

I Parienty
F Jouniaux

Breakthrough techniques for non-contrast MRA investigations of peripheral and renal arteries in patients with renal insufficiency

The gold standard for the investigation of occlusive peripheral and renal arteriopathies in ischemic nephropathy and/or renovascular hypertension has traditionally been classic arteriography. However, this technique is relatively invasive, and in recent years has been used solely for visualization during revascularization procedures. In diagnostic workup where endovascular or surgical management is envisaged, arteriography has been replaced by magnetic resonance angiography (MRA) and computed tomography angiography (CTA), reliable imaging modalities which allow for vascular mapping comparable to classic angiography.

Although CTA results have been excellent since the advent of 16- and 64-slice multidetectors, radiation exposure and the intravenous (i.v.) iodine contrast agent associated with the procedure often make contrast MRA a more appealing option for the patients who are often polyvascular, diabetics or suffer from renal insufficiency.

A recent report of nephrogenic fibrosis being induced by gadolinium in patients with moderate to severe renal insufficiency underscores more than ever the need to realize high quality, contrast-free vascular imaging by MRA, and to rethink the exploration strategy for these peripheral vascular lesions.

Innovative non-contrast MRA techniques known as FBI (Fresh Blood Imaging) and Time-SLIP (Time-Spatial Labeling Inversion Pulse) by Toshiba have been available for clinical use for several years in Japan and for nearly one year in France, using the new Toshiba 1.5 T MRI systems Vantage and Vantage powered by Atlas. Both systems offer a high quality and a totally safe alternative for pre-therapy assessment of occlusive arteriopathies in the peripheral and renal arteries.

Occlusive arteriopathy in the lower extremity

This common pathology, which is associated with a high level of morbidity, requires precise information on the degree of stenosis, its localization and the extent of the lesions prior to revascularization procedures.

Although echo-enhanced Doppler sonography provides morphological and hemodynamic information, the examination is lengthy, complex, often incomplete and does not map the area of interest as good as classic angiography. Nevertheless, it is still many surgeons' modality of choice. CTA has emerged as an efficacious tool combining outstanding spatial resolution with high-speed acquisition, thus reducing the required amount of contrast agent and avoiding venous return at the popliteal artery trifurcation. In the evaluation of stenoses, CTA has a sensitivity and specificity of approximately 95%. Although visualization of calcifications is useful, it sometimes interferes with the evaluation of stenoses.

The major drawback of CTA is radiation exposure and its inherent need for iodine contrast agents which may induce or exacerbate nephropathy.

Contrast-enhanced MRA has revolutionized patient workup since, if carried out correctly, it provides quality images on a par with those generated by classic angiography, and also with a sensitivity and specificity of approximately 95%.

The main technical difficulties in CTA can be summarized as follows:

- overestimation of the degree of stenosis
- artefacts occasioned by calcification or metal (stents)
- venous contamination
- impregnation of the tissue with gadolinium.

FBI should therefore be evaluated against CTA or gadolinium-MRA. This technique constitutes a FASE (fast advanced spin echo) sequence and uses an ECG gated half-Fourier acquisition in T2.

Two acquisitions are synchronized by ECG as follows: (a) in systole, where only the veins exhibit a hypersignal since arterial flow is too rapid; and (b) in diastole, where both the veins and arteries exhibit a hypersignal.

The automatic subtraction of the two images allows for visualization of the arteries alone. This technique may overestimate the degree of stenosis and may present artefacts due to the presence of calcium, metal (stents), peristalsis around the iliac artery. Furthermore, it could be sensitive to patient motion between the acquisitions of the two phases as it leads to misalignment of the two images and thus incomplete subtractions.

The examination is performed in four successive cycles from the infrarenal aorta to the plantar arcade and takes about 40 minutes in total on a Vantage XGV system.

Comparative study of clinical cases

The cases described below involved the performance (at our imaging center) of either FBI in conjunction with CTA or contrast-MRA which was either requested by the referring physician or was planned from the outset because of renal insufficiency.

Case 1

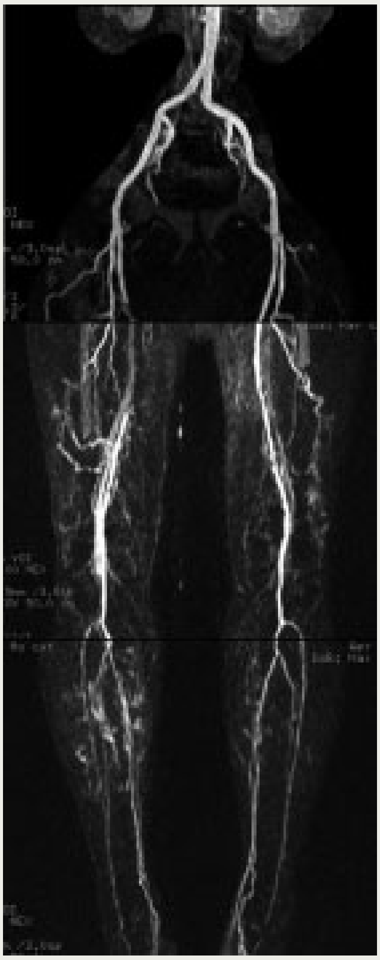
82-year-old male patient with normal renal function who was referred for evaluation of an incomplete stenosis of the right femoral artery suspected in echo-enhanced Doppler scanning of the lower limbs.

After obtaining the consent of both the patient and the referring physician, we performed gadolinium-MRA as well as FBI.

The three modalities yielded comparable results for evaluation of the right femoral artery occlusion, with good resumption of downstream flow and collateral circulation via the deep femoral artery. Owing to the presence of numerous calcifications, both MRA modalities allowed for better visualization of vessal wall irregularities in the remainder of the arterial bed.

Visualization of the popliteal artery trifurcation was better with FBI than with CTA (possibly owing to an injection timing problem in this patient attributable to the slow flow rate of contrast agent through the peripheral arteries) or gadolinium-MRA, where the images were corrupted by venous return. Due to overall tissue enhancement following the gadolinium injection the signal-to-noise ratio was poor.

CT angiography



Gadolinium-MRA

FBI

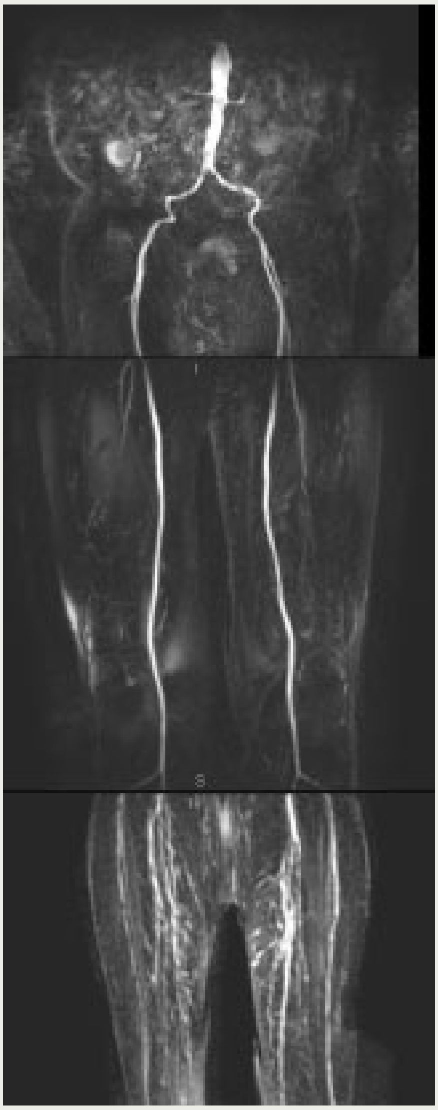
Case 2

67-year-old polyvascular male patient with normal renal function who was referred for CT angiography scanning of the peripheral arteries and in whom we also performed FBI MRA with the patient's consent.

The quality of the study was essentially identical with the CTA from the infrarenal aorta to the popliteal arteries, but was far poorer at the level of the popliteal artery trifurcation, probably owing to patient movement between acquisitions which occasioned incomplete subtractions and venous signal corruption. In order to avoid the generation of artefacts which may make the images difficult to interpret, the patient must remain perfectly still during the procedure.

FBI revealed numerous vessel wall abnormalities in the iliac artery region consistent with the calcifications detected on CT angiography.

CT angiography



FBI

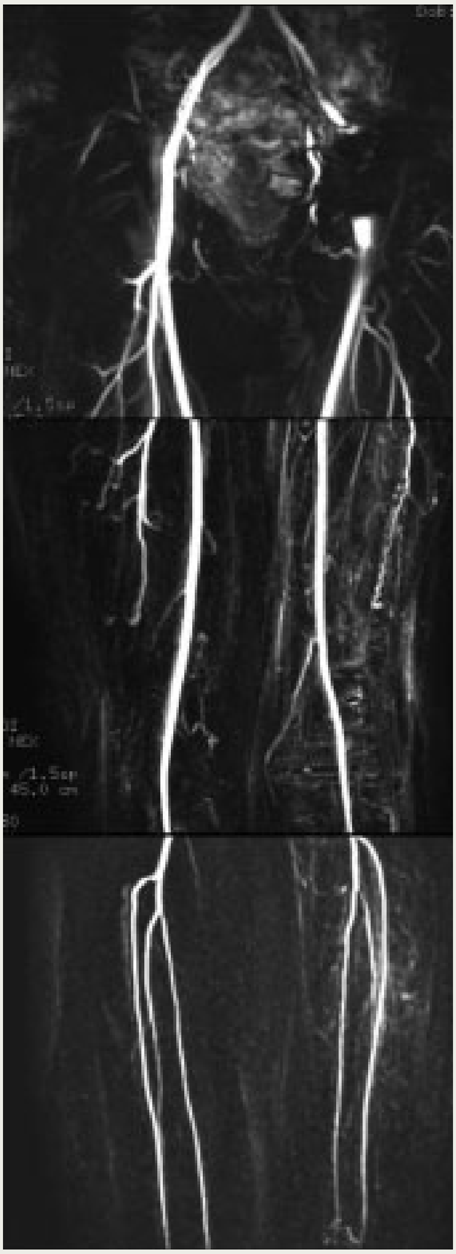
Case 3

Male patient presenting with sensitivity problems in the left leg as well as acute trauma due to a traffic accident.

Multiple fractures of the pelvis and left femur and a femoral artery lesion, necessitating vascular surgery and total hip replacement accompanied by osteosynthesis of the acetabulum and the distal femur. Two MRAs were performed with gadolinium and in FBI mode.

Both techniques yielded the same visualization of the arterial axes. The metal artefacts were more severe with FBI but following injection of gadolinium artefacts were observed resulting from tissue impregnation and venous return in the region of the left thigh.
No significant lesion was observed which could have explained the symptoms.

MRA with gadolinium

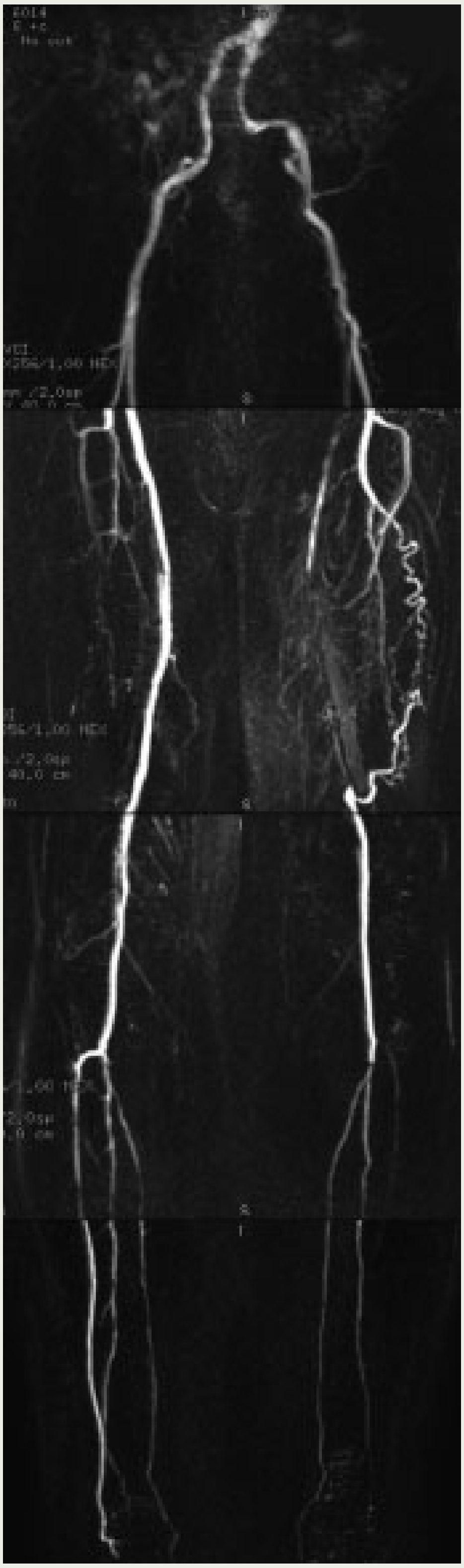


FBI

Case 4

65-year-old polyvascular male patient presented with coronary pathology (scheduled for stenting).

Stenosis of the left superficial femoral artery (detected on echo-enhanced Doppler sonography) and renal insufficiency. The patient also complained about pain in the left leg and foot.
Due to the patient's renal insufficiency, a whole-body non-contrast MRA was performed. The peripheral arteries were investigated by FBI and the renal arteries underwent a Time-SLIP study (see below).
The quality of the FBI study was good in all segments. Complete occlusion of the left superficial femoral artery was observed with good resumption of flow downstream and collateral circulation via deep femoral artery. At the left popliteal artery trifurcation complete occlusion at the level of the middle third of the anterior tibial artery was observed, with very sluggish flow in the first third of this artery. We also detected a significant short and dense stenosis at the origin of the tibioperoneal trunk, with substantial reduction in downstream flow in the peroneal and posterior tibial arterial tree due to this pathology. Simple vessal wall irregularities were detected in the right leg.



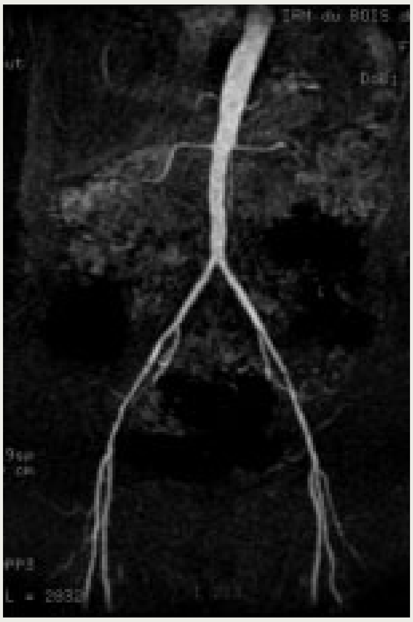
MRA without contrast agent

Case 5

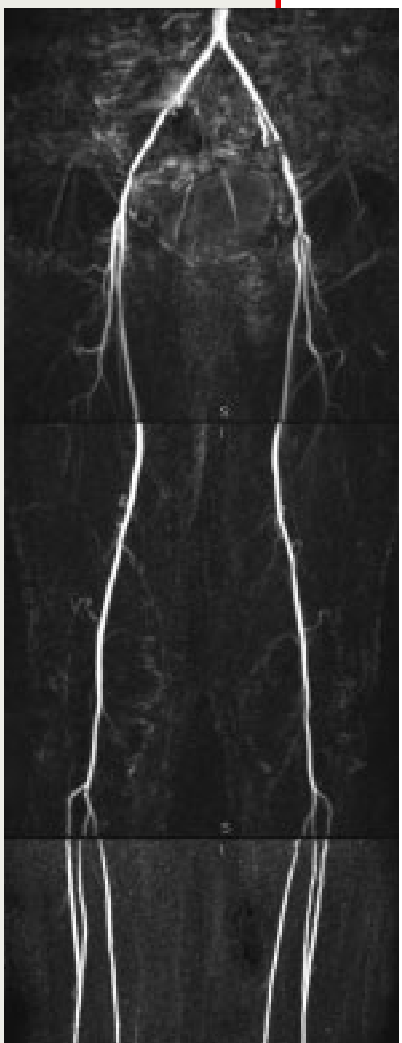
70-year-old female polyvascular patient presented with coronary artery disease and peripheral arterial occlusive disease (previously studied in 2006 by CTA) with intermittent claudication.

No renal insufficiency was observed. Contrast-agent MRA and FBI were performed and the images obtained were compared with the previous angiography scans. The FBI examination yielded satisfactory image quality in all segments.

Due to motion artefacts in the other segments, the MRA results were meaningful only for the iliac arteries.
Both modalities revealed a minor stenosis on each external iliac artery with a good downstream flow but more constricted in the left leg. This stenosis appeared larger on FBI and was of the same size on CTA and contrast-enhanced MRA.



MRA with gadolinium



CTA

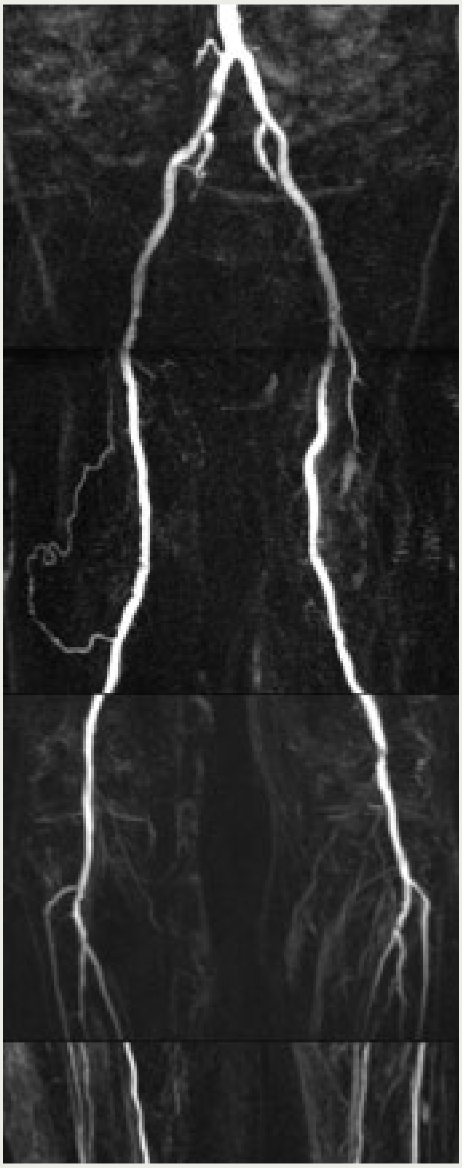
FBI

Case 6

59-year-old male patient presented with lower extremity pain and an atheromatous plaque visualized on echo-enhanced Doppler sonography.

A CTA study was performed, followed by FBI MRA. Both examinations yielded high image quality results.
CT angiography revealed numerous vessel wall calcifications in the infrarenal aorta and the common iliac arteries. We also observed numerous wall pathologies, attributable to soft atheromatous plaques. No significant stenosis was observed, but the right superficial femoral artery exhibited a greater amount of plaque, with a collateral artery originating from the deep femoral artery supplying the superficial femoral artery further downstream. This collateral artery was more pronounced on FBI than on CTA, whereas the deep femoral artery was less visible. Furthermore, a larger plaque in the left popliteal artery was much better seen on the FBI images because of its calcification.

CTA



FBI

Studies of the renal arteries

The renal arteries are investigated in patients with suspected renal hypertension and/or ischemic nephropathy and for whom endovascular or surgical revascularization is an option.

The main objective when revascularizing renal atheromatous stenosis is the preservation of renal function.

Atheromatous disease affects the renal arteries diffusely up to the most distal branches and in some case revascularization fails to improve renal function.

For bilateral stenosis of at least 60%, generally one has to choose between the more common therapeutic options of angioplasty and stenting or left splenorenal and right hepatorenal bypass respectively, which are performed far less frequently. The risk entailed by revascularization (obstruction, dissection of the renal artery, renal infarction, deterioration of renal function) increases in those cases where atheromatous plaques involve the aorta and the coronaries. Hence the diagnostic strategy in such cases is of utmost importance.

Diagnostic imaging should delineate the severity, extent and localization of the stenoses, visualize the most distal arterial segments, detect all collateral renal arteries (which may arise anywhere between the suprarenal aorta and the iliac arteries) and evaluate the renal parenchyma.

The main drawback of CTA is its need for the injection of iodine which entails a high risk of induced nephropathy. However, CTA provides outstanding spatial resolution and detecting calcifications can be useful for stent implantation as well as for follow-ups after stenting.

Gadolinium-MRA is realized in frontal acquisition mode so as to allow for visualization of the entire aorta from its suprarenal segment down to the common iliac arteries, with a large field of view. CTA detects ostial and proximal stenoses (which are most common) with nearly 100% sensitivity and a specificity of 75-100%, but visualizes the arterial trunks and distal branches poorly. Artefacts due to calcifications and stents are also seen with this method. Until recently, before some gadolinium-based contrast agents were linked to renal toxicity, gadolinium-based contrast-enhanced MRA was considered a totally safe technique in patients with renal insufficiency.

Time-SLIP (Time-Spatial Labeling Inversion Pulse), an innovative non-contrast MRA modality available from Toshiba, allows for the imaging of selective vessels via prior marking (tag pulse).

3D acquisition is realized via a rapid sequence of images in T2.

A pre-saturation band is placed under the acquisition volume so as to separate the arterial and venous blood flow.

A complete study entails axial acquisition for optimal visualization of the distal segments of the main renal arteries and acquisition in the coronal plane for visualization of the entire abdominal aorta down to the common iliac arteries, in order to detect all collateral renal arteries. A third sequence is also carried out in order to assess parenchyma status of the kidneys.

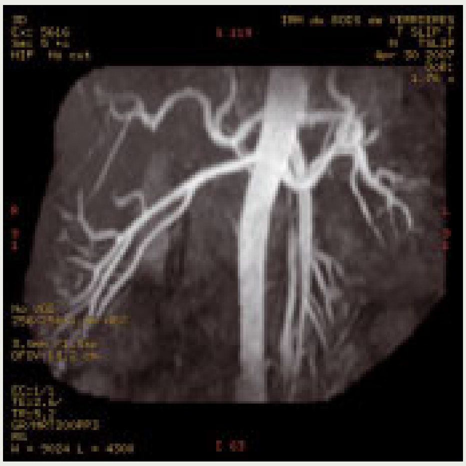
Clinical cases

Case 1 was an examination of a healthy volunteer, on whom a complete Time-SLIP investigation of the renal arteries was carried out. Cases 2-4 show patients suspected with renal stenosis.

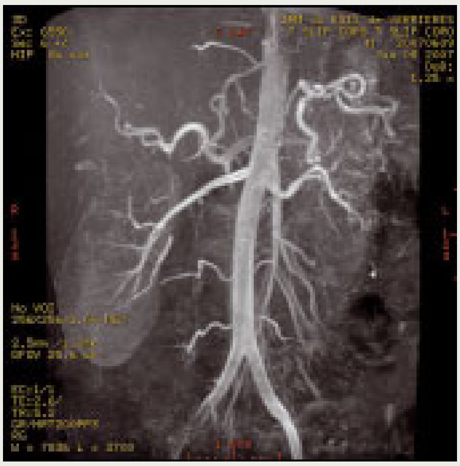
Case 1

Examination of a healthy volunteer permitting complete evaluation of renal vascular status.

The Time-SLIP modality allows for accurate imaging of the distal renal arteries, as well as the renal parenchyma and the entire aorta down to the iliac arteries.



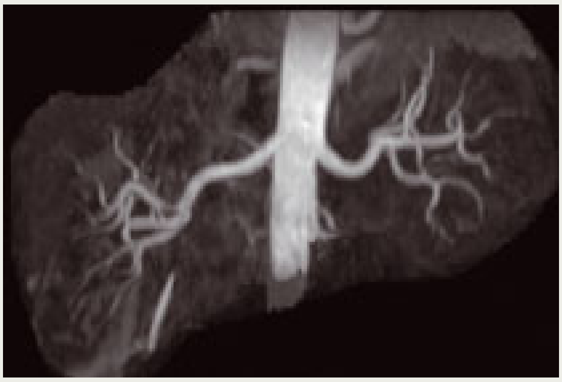
Time SLIP - axial acquisition



Time SLIP - coronal acquisition

Case 2

A 35-year-old female patient referred for MRA evaluation of her hypertension. The study consisted of a gadolinium-enhanced MRA and a Time-SLIP, in axial acquisition centered on the renal arteries. Comparison of both modalities demonstrated that the distal renal arteries were far better seen on Time-SLIP. No significant abnormality was observed.



Time SLIP - axial acquisition

Case 3

A 68-year-old male patient with poorly controlled hypertension who presented with acute renal insufficiency. Echo-enhanced Doppler sonography provided no useful information in this case and thus diagnostic contrast-free MRA was performed. For each kidney, Time-SLIP revealed one principal renal artery and a collateral upper polar artery of sufficient lumen. We observed a significant ostial stenosis of the main right and left arteries with satisfactory preservation of distal flow; the distal arteries were well depicted. After seeking an expert opinion and despite the patient's poor overall vascular status and the presence of slightly atrophic renal parenchyma, the patient underwent endovascular revascularization during which both main renal arteries received a stent.

Time SLIP - axial acquisition

Case 4

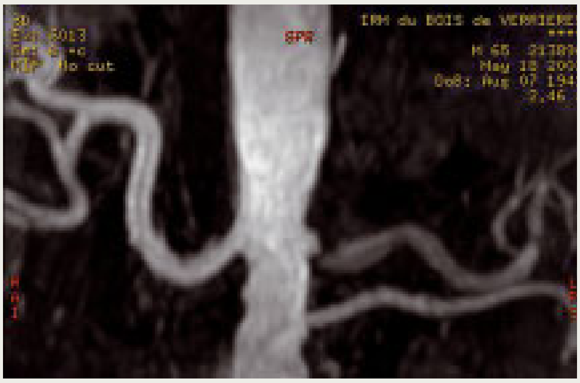
Same polyvascular patient as in the FBI case 3 above. *Because of his renal insufficiency, only Time-SLIP could be used to explore his renal arteries.*

This investigation revealed a right main artery with atheromatous ostial plaque with an irregular lumen size but no significant stenosis; the downstream flow and depiction of the distal branches were both satisfactory.

Time SLIP - axial acquisition

Case 4

A significant ostial stenosis with substantially diminished downstream flow was detected in the main left artery and inferior polar artery. A substantial number of atheromatous plaques were detected in the suprarenal and particularly in the infrarenal vessels.



The renal parenchyma was normal.

This patient was explored and treated by endovascular stenting of the ostial stenosis of the main left artery.

Outlook

Studies of other lesions in these vessels (e.g. aneurysms, dissections, fibrous dysplasias) could also be realized and other applications seem promising, particularly arterial investigations of the hands and feet using FBI, as well as Time-SLIP exploration of the portal system and the pulmonary arteries, coronary imaging and dynamic imaging of the carotid arteries.

Prospective randomized studies are needed in order to evaluate the sensitivity and specificity of these modalities in the detection and assessment of peripheral arterial stenoses.

Once the operator has acquired a modicum of experience with these modalities, studies of consistently high quality can be realized and the main artefacts avoided.

Hence, based on the clinical cases presented here, with Toshiba's non-contrast imaging modalities which can successfully perform MRA – fresh blood imaging (FBI) and Time-SLIP – the results are comparable to those obtained by CTA and gadolinium-MRA.

When combined with Toshiba's MRI Vantage and Atlas scanners, these modalities appear to be sufficiently reliable for the study of peripheral and renal arterial lesions in patients with moderate to severe renal insufficiency. These modalities represent a significant breakthrough since in these patients, the standard diagnostic options are barred due to the risk of iodine-induced nephropathy associated with CTA and the risk of irreversible gadolinium-induced nephrogenic fibrosis associated with MRA.

References
- Vascular and interventionnal Radiology, Karim VALGI (Saunders)
- Angiographie par resonance magnétique, Philippe DOUEK, J.P. LAISSY, C.LIM, H.TRILLAUD (Masson)
- Imagerie des artériopathies des membres inférieurs hors Echo-Doppler, Serge Willoteaux, (sang, thrombose , vaisseaux vol.18 n°5 mai 2006)
- Aortoiliac and renal arteries : prospective Intraindividual Comparison of contrast-enhanced Three-dimensionnal MR Angiography and multi-detector Row CT Angiography, J.K. WILLMANN, (Radiology 2003;226:798-811)
- 16 Detector Row CT Angiography in peripheral Arterial Disease: Randomized Controlled Trial, M.C.J.M. KOCK, (Radiology, November1,2005; 185,5: 1261-1267)
- DSA versus Multi-Detector Row CT Angiography in peripheral arterial disease Randomized Controlled Trial, M.C.J.M. KOCK, (Radiology,November 1 ,2005 237(2) 727-737)
- Quantitative Vascular Measurements in Arterial occlusive Disease, H. OTA, (Radiographics, September 1 2005 25(5) 1141-1158)
- Aorto-Iliac and lower extremity arteries Assessed with 16 Detector Row CT Angiography: Prospective Comparison with Digital Substraction Angiography, J.K. WILLMANN, (Radiology September 1 2006 236(3) 1083-1093)
- Peripheral Arteries in Diabetic patients: Standart Bolus-Chase and Time-Resolved MR Angiography, G.ANDREISEK, (radiology, December 19 2006)
- Vessel Wall Calcifications and Multi-Detector Row CT Angiography in patients with Peripheral arterial disease. Effect on Clinical Utility and Clinical predictors, R.OUVERDIJK, (Radiology, November 1 2006, 241(2) 603-608)
- Imaging Peripheral Arterial disease : a randomized controlled trial comparing contrast enhanced MR Angiography and Multi-Detector Row CT Angiography, R.OUVERDIJK, (Radiology, Sptember 1 2005,236(3), 1094-1103)
- Contrast enhanced MR Angiography of the renal arteries; Blinded Multicenter crossover comparison of Gadobenate Dimeglumine and Gado Pentetate Dimeglumine, M.PROKOP, (Radiology February 1 2005, 234(2) 399-408

Dr Isabelle Parienty
F Jouniaux
Centre d'Imagerie du Bois de Verrière
48, rue du Colonel Fabien
F- 92160 Antony
France

ARTIDA

T Yoshie

Improving clinical performance with innovative technology

Introduction

Higher expectations in routine echocardiography, new quantification and visualization techniques and the ever increasing demand for workflow and ergonomic solutions present many challenges to the development of an echocardiography system. In particular interest in 4D ultrasound is driving changes to system architecture, transducer design and raw data processing capability.

Toshiba's development of Artida™ required innovation in all aspects of ultrasound system design. It was very important to have good clinical input before developing this new technology. Establishing a Medical Advisory Board and user groups were the most important first steps. Strong demand for imaging performance, advanced applications, workflow innovation and ergonomics drove the development of a new range of technologies that significantly impact system performance.

State-of-the-art transducer technology

Conventional transducers feature a row of transducer elements which generate a two-dimensional image. In recent years transducers with subdicing of the elements and electronic switching to vary the receive element characteristics known as 1½ D array (or sometime matrix) transducers have been used to minimize beam thickness in 2D scanning. Also in some applications 3D and 4D scanning has been achieved by rapidly sweeping a 1D array transducer across a volume mechanically. However, frame rates and footprint have not been satisfactory for cardiac applications in such transducers.

In order to generate high-quality four-dimensional imaging with excellent image quality, temporal resolution and control flexibility a true matrix transducer approach is required. By being able to trans-electronically control the excitation of a two-dimensional array of ceramic elements rapidly over time a 4D wave pattern can be created. Similarly a 4D volume can be created by carefully processing the signal received over this array.

Furthermore, ergonomic requirements dictate that such a transducer be compact and lightweight. In particular the length of transducer must be minimized in order to make apical imaging easier. Limited space between patients' ribs dictates a small footprint.

To achieve these requirements a new class of transducers is required. SmartFocus technology was developed specifically to meet these requirements. New piezo-electric materials provide greater sensitivity and resolution by increasing the bandwidth of the transducers. Sensitivity is also improved through new heat dissipation technology and low attenuation lenses employing nanotechnology materials.

New materials, smaller subdiced elements, transducer reliability, heat loss characteristics, transducer size and weight limitations mean making such a

Fig. 1: SmartFocus Cardiac 4D transducer. The smallest, lightest, highest performance 4D transducer to date

Fig. 2: SmartFocus Cardiac 1D array transducer

transducer is not easy. A whole new range of machining and assembly techniques had to be developed in order to make the transducer a reality. The result is the PST-25SX, the smallest (and importantly, shortest), lightest, highest performing 4D transducer available today.

Many of the improvements that enable 4D transducer can also be applied to 1D array transducers. New materials and new manufacturing techniques mean SmartFocus 1D array transducers also feature improved performance in smaller, more ergonomic designs. In particular new machining techniques make it possible to create elements that can vary the beam profile over depth.

SmartFocus transducer design is an integral part of Artida's system performance, however extracting the most from these more sophisticated transducers requires a new beamformer, advanced processing techniques and substantially more computational power.

High-performance beamformer and processing engine

Driving a SmartFocus transducer and processing the volume and complexity of signal data returned is far more challenging than in a conventional echocardiography system. It would not be possible without the development of the MultiCast beamformer and the SmartCore processing engine.

The MultiCast beamformer is responsible for creating an ultrasound beam that can scan 2D and 4D anatomy more quickly and more accurately. The complexity of the wave pattern generated and the high temporal resolution at which it is created require that it be fast and flexible. It contains a number of innovations. It can simultaneously generate waves patterns that focus at different depths thus allow dual focal points in an image without sacrificing frame rate. The MultiCast beamformer can simultaneously transmit/receive Doppler data to/from different destinations enabling increased color Doppler temporal resolution. In particular small regurgitant jets can be detected when this increase is combined with the greater sensitivity of SmartFocus transducers.

Fig. 3: Artida

SmartCore is the new architecture that provides the raw data processing power required to drive the beamformer and transducers and to provide high quality data to the display and advanced applications that make this data meaningful. It combines over 80 high-performance processors with large

Fig. 4: Tissue Enhancement Mode enhances myocardial definition

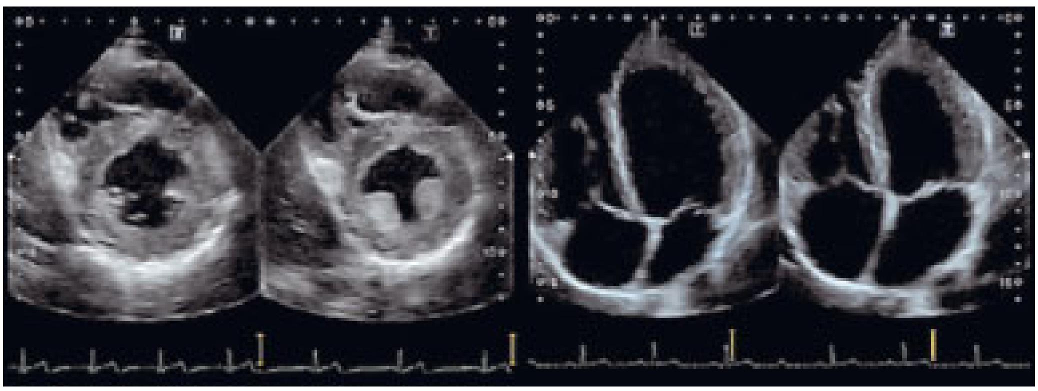


Fig. 5: 2D Wall Motion Tracking

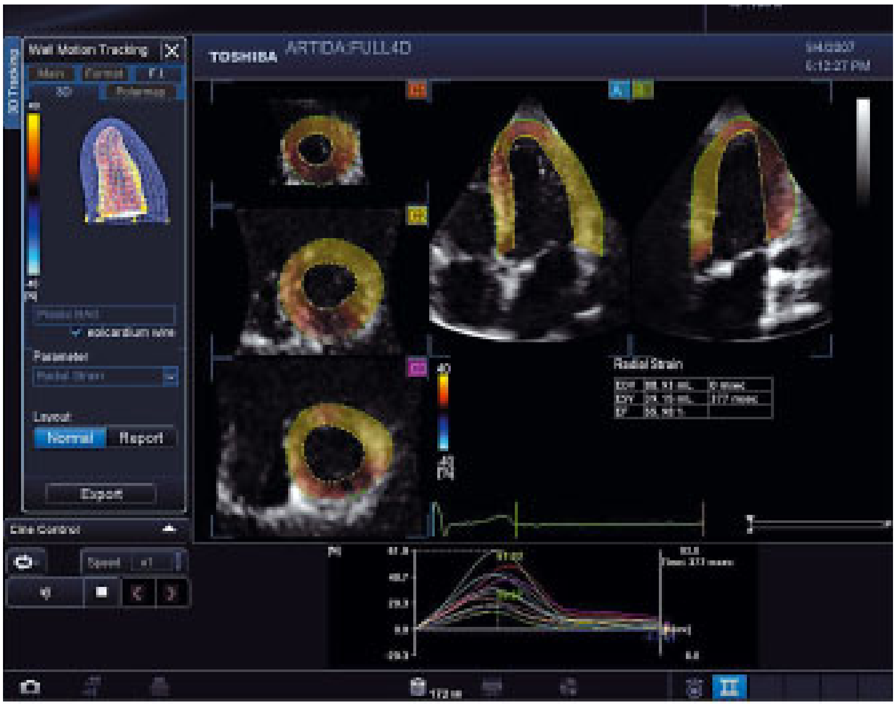


Fig. 6: 3D Wall Motion Tracking

scale Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) and high speed Digital Signal Processors (DSPs). The design objective is to provide the fastest, most flexible possible architecture for the processing of complex information. SmartCore can process massive amounts of information and extract the clinical parameters necessary for clinical assessment and diagnosis.

The increased performance of SmartCore allows numerous, previously impossible image processing techniques to be applied. For example, Tissue Enhancement Mode offers a smoother, clearer ultrasound image than was previously achievable. The noise is effectively suppressed, and the uniformity of the image and the visibility of the endocardium and myocardium are greatly improved.

SmartCore is also highly configurable enabling fundamental system performance and functionality to be upgraded in software.

Advanced clinical applications

High quality data means excellent imaging performance. Increasingly echocardiographers are also asking for advanced applications. Cardiovascular disease is a leading cause of death and is becoming

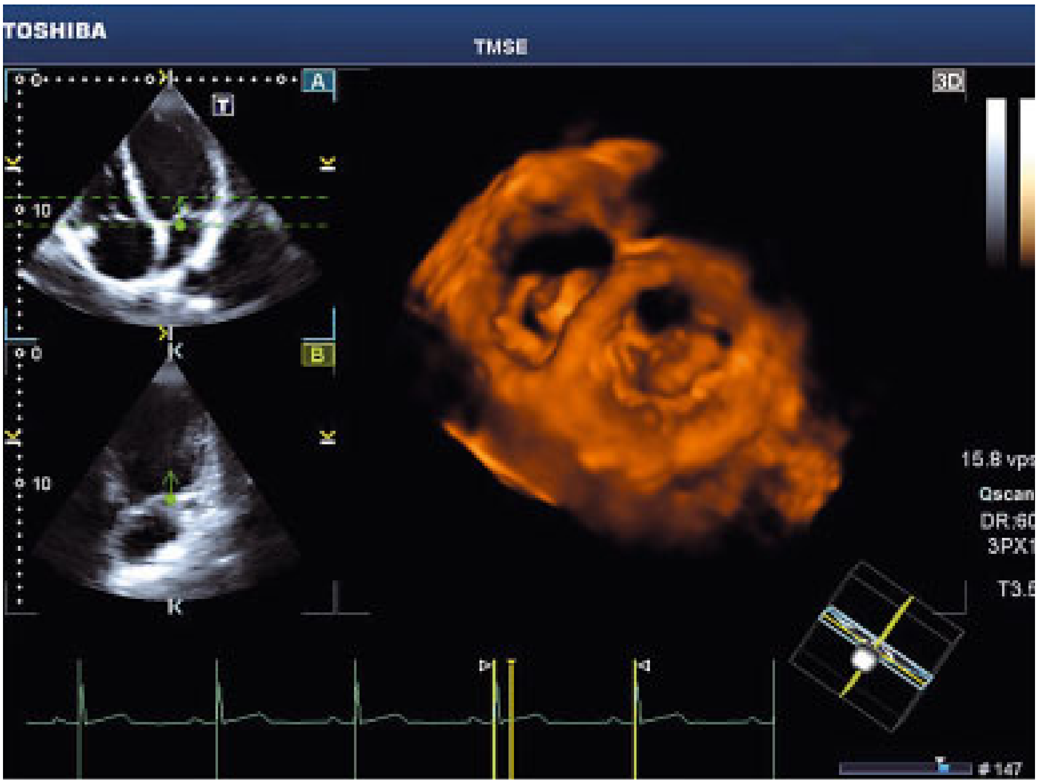


Fig. 7: SmartSlice plane selection

more frequent. Disease which affects wall motion and its timing can be difficult to detect with the naked eye. Of late quantitative applications have been of particular interest because they offer the promise of earlier, less subjective assessment of cardiovascular disease.

Pattern matching techniques, widely known as speckle tracking, allow detection and quantification of wall motion. Wall Motion Tracking can be used to assess abnormal motion often seen in ischemic heart disease. Such abnormal wall motion can be observed even when it is not apparent to the eye. Regional and global motion can be assessed and a wide range of parameters can be observed like displacement, velocity, strain, strain rate, rotation, etc. These techniques are not subject to the directional limitations of Doppler techniques which depend on the angle of incidence of the ultrasound beam to the moving tissue. Semi-automated tracking techniques means the total myocardium can be quickly identified and assessed and a range of quantitative results and graphical representations can be generated.

Artida features two methods of Wall Motion Tracking: 2D Tracking (2DT) tracks 2 dimensional wall motion (the projection of three-dimensional movement on a two-dimensional plane). 2D Tracking can generate high temporal resolution data useful for techniques such as dyssynchrony evaluation.

3D Tracking (3DT) can observe total, global myocardial movement. 3DT is not easily achieved due to the very large number of speckles that must be identified and tracked spatially (throughout the myocardium) and temporally (throughout the cardiac cycle). It is not possible to achieve 3DT by simply conducting 2DT on multiple planes. New data processing techniques including 3D speckle tracking templates had to be developed. SmartCore Engine processing power is the key in this technique. With a full quantifiable volume available, true global assessment of the myocardium can be made and new parameters (like twist, torsion, etc.) can be observed.

The importance of ergonomics and workflow optimization

Ergonomic and workflow considerations are increasingly important in ultrasound design. Minimizing repetitive, unnatural operator movement and reducing the time and effort required to conduct an exam are central to Toshiba's ultrasound design philosophy. Since 4D is a relatively new technology, it was an area of particular focus in terms of ergonomics and workflow.

There are many considerations in making an ergonomic system. Toshiba's ergonomics philosophy is embodied in the iStyle™ concept. It starts at the control panel. Frequently used operations are arranged around the central palm controller so they can be activated with minimum movement. The whole panel is highly configurable. Key assignments can be changed so that frequently used functions can be added to the panel and positioned according to the operator's requirement. A much greater range of functionality is available at the Touch Command Screen. The placement of controls of this screen is also fully customizable. QuickScan one touch image optimization can also substantially reduce key usage. The whole panel can be moved left/right, in/out and up/down and the monitor can be positioned independently. A handle was added to the monitor to make it easy to position. The system is very quiet in order to improve both the operator and patient experience.

There are many workflow and ergonomic challenges in 4D ultrasound. 4D transducers are by necessity larger, there are multiple steps required to assess the data and the practice of 4D is still changing

Fig. 8: iStyle ergonomics

erations by selecting an observer point in the first and then a view direction and slice thickness in the second.

One difficulty with 4D in cardiology applications is the trade off between temporal resolution and image quality. On Artida it is possible to acquire a complete cardiac volume in one heartbeat. This method provides a very consistent dataset. If users require higher image quality or better frame rates then its possible to acquire the volume over several heart cycles and synthesize a complete volume. A real time display was chosen for this function so that as each data segment is updated the volume is continually displayed. This makes it much

quite rapidly. As the usage of 4D increases, the importance of these issues will likely increase so its important to pay close attention to them on a new platform.

4D transducer design is discussed above in greater detail but the main ergonomic considerations are weight, size (especially length) and footprint. The PST-25SX transducer is the lightest and smallest (and shortest) in class, the cable is lightweight, flexible and long so its very well suited to ergonomic and workflowrequirements in clinical usage.

Since QuickScan one touch image optimization is well accepted in 2D echo it is a very worthwhile addition to 4D. It allows rapid optimization of the image quality of the entire volume in one operation.

While a lot of data is available in a 4D volume, extracting the information from that volume can involve multiple steps. Minimizing the operations required offers the possibility of substantial gains over existing 4D solutions. SmartSlice technology was specifically developed to make obtaining results in 4D imaging faster and easier. SmartSlice provides a variety of tools for 4D data manipulation with a focus on simply and quickly achieving the desired view. For example 4D plane selection is reduced to two op-

easier to monitor the volume for quality before storing or analyzing it. Irregularities caused by patient movement or breathing can more easily be avoided.

Conclusion

Artida features changes to nearly every aspect of echocardiography system design. Far more important than the technical innovation though, is the definition of clinical requirements that these innovations must address. Through close consultation with the Medical Advisory Board and users we could ensure that the new design was targeted at real clinical and research requirements. Artida's basic design philosophy centers on advanced transducer design to provide better data, faster and more flexible signal processing to extract more information more quickly, improvement to conventional clinical applications and new advanced applications. At every level attention to workflow and ergonomics are an overriding factor.

The final result is improved clinical performance and a host of tools that provide new ways to assess 2D and 4D ultrasound data.

**Artida and iStyle are trademarks of Toshiba Medical Systems Corporation*

T Yoshie
Toshiba Medical Systems Corporation, Tochigi, Japan

TOSHIBA
Leading Innovation

The world has been waiting for this.

ONE Rotation
ONE Phase
ONE Volume
ONE Scan

Aquilion ONE