Siemens Healthineers Historical Institute

The history of computed tomography at Siemens Healthineers

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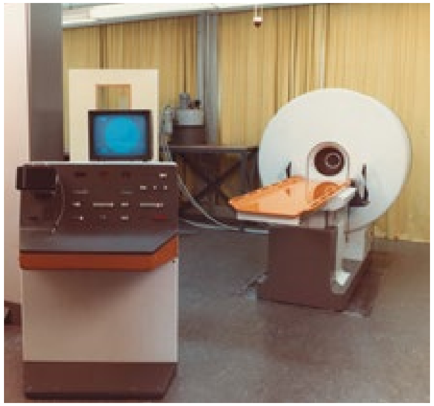
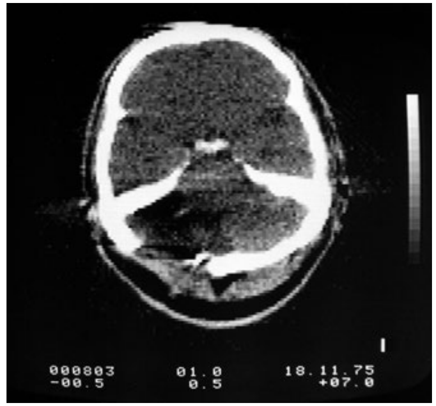




Content

“Röntgen must be crazy”

Modern medical technology unlocks fascinating views inside the human body. Medical imaging allows physicians to visualize both the morphology and the function of the human body in detail. The clear images of pathological changes or injuries that this makes possible represent a huge contribution to diagnosis and treatment guidance today. Depending on the requirements in the specific case, highresolution images of any part of the body – from the crown of the head to the soles of the feet – are available. These images can then be used to filter out the information of medical interest and present it optimally using sophisticated data-processing algorithms. But 120 years ago, physicians still had to rely on external signs and symptoms – or on a surgical scalpel – to identify injuries and certain diseases. That changed on November 8, 1895, with what is still the most important discovery in the history of medical technology: Wilhelm Conrad Röntgen, a physicist, discovered X-rays.

Late that evening, Röntgen was working at his lab in the city of Würzburg. He was experimenting with a vacuum tube made of glass, which he was using to generate beams of electrons. He wrapped the tube in black paper so that he would not be disturbed by the light generated by the electric discharge occurring in the gas inside it. But when Röntgen started his experiment in the darkened lab, a coated paper that happened to be lying near the tube began to glow brightly. Röntgen was astonished – it definitely couldn’t be ordinary light. He placed a thick book between the tube and the paper, but the rays simply passed through it. Röntgen then held his hand up to the strange rays and made the most exciting discovery of his life: The coated paper showed the shadowy outline of the bones in his hand!

Röntgen was not the first scientist to observe these rays – but he was the first to recognize their importance and study the phenomenon scientifically. In the beginning, he kept his observations to himself, spending several weeks on further research on his own. “I didn’t tell anyone anything about my work; I told my wife that I was doing something that, if people heard about it, would make them say, ‘Röntgen must be crazy.’”

Röntgen’s wife was named Bertha, and part of her body has become world-famous. To be able to offer proof of his discovery, Röntgen X-rayed her hand and captured the image on a photographic plate. On January 1, 1896, he published his work with a few photos as evidence in an insert in the report on the meeting of the Würzburg Physikalisch-Medizinische Gesellschaft. The title of his treatise: “On a New Kind of Rays.” Not long afterward, as he had expected, “chaos broke out.” The news of his sensational discovery spread around the world in just a few days. Scientists were thrilled, and even laypeople celebrated the discovery. As “X-ray fever” caught on, anything and everything was X-rayed: Coin purses, doors, furniture – and most of all, human bodies. Unlike in conventional photography – from the Greek photos, for “light,” and graphos, for “drawing” – early X-ray images were more like shadow images. Röntgen became a household name, and also the word for “X-ray” in German. Particular acclaim came from Sweden: Röntgen was awarded the first Nobel Prize in Physics in 1901.

Bertha Röntgen’s hand, 1895

Source: Deutsches Röntgen-Museum

X-rays had already become an integral part of modern medicine by then. Around 1900, X-ray technology had advanced beyond merely providing images of the skeleton; it could also be used to see inflammations, gallstones, and foreign bodies. For the first time ever, doctors had a way to detect the early stages of what was then the most common cause of death in the Western world: Pulmonary tuberculosis. At the same time, numerous X-ray pioneers were at work on new examination methods and improved equipment. Over the years, X-ray images have become so clear that they also show soft tissue. Special contrast agents injected into a patient’s bloodstream ultimately even made it possible to visualize the vascular system.

Right from the start, the predecessors of Siemens Healthcare played a major role in these ongoing developments and improvements. As early as January 1896, Siemens & Halske began developing an X-ray tube that could also be used for medical purposes. Max Gebbert, the owner of the Erlangenbased firm Reiniger, Gebbert & Schall, also recognized the potential of X-ray technology right away. Just three days after hearing of Röntgen's discovery, he sent an engineer to Würzburg to learn more about the new rays.

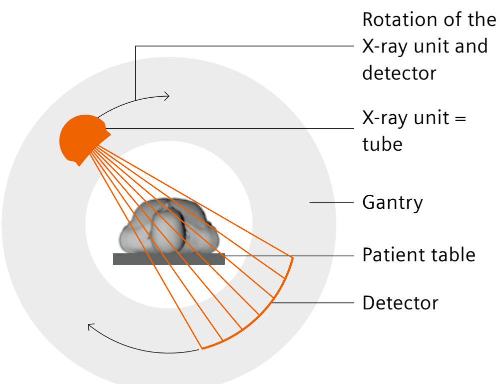
Just under 80 years later, a new technology sparked great fascination in the medical community, much as the first X-ray images had done before. Computed tomography (CT) is also based on X-ray technology, but it visualizes the inside of the body onscreen, one slice at a time. This method can be used to locate tumors, hematomas, and internal injuries with great accuracy. In conventional X-ray images, different structures are superimposed on each other; images ofthe lungs, for example, are affected by the structures of the bones. This means that X-ray images depict minor differences in density between different kinds oftissue poorly, if at all. The "slice images" produced by computed tomography, however, present slices of the body without superimposition, as if individual sections had been taken out of the body. In advanced systems, these slices are just 0.5 to 1 millimeter thick, allowing doctors to see even the tiniest changes in tissue.

Siemens launched its first CT system in 1975. The SIRETOM cranium scanner generated tomographic images of the brain, taking just under five minutes per scan. Development advanced rapidly. Just two years later, a head scan using the Siemens SOMATOM whole-body scanner took only five seconds. Today's high-performance systems are even faster, and they also offer far superior image quality. A lot has happened in the 40-year history of computed tomography at Siemens. It is a history packed with discoveries, inventions, and innovations.

Wilhelm Conrad Röntgen, 1900
Source: Deutsches Röntgen-Museum

What is computed tomography, and what are its strengths?

Conventional X-ray systems beam rays through the body, visualizing bones and tissue on special X-ray film. In the process, structures in the path of radiation are shown super- imposed. Computed tomography, by contrast, measures the weakening of X-rays within the tissue, visualizing the inside of the body as tomograms – slice images – on a screen. The CT scanner "slices" the body into thin sections. In principle, this is much like slicing a marble cake, which provides a detailed picture of just where the dark and light mixtures are distributed inside the cake. The medical images offer a detailed, highcontrast view of the tissue inside the body. This has significant advantages for many clinical questions: They are free of superimpositions, so the image is not affected by other bodily structures; the body is shown with spatial depth and can be viewed as a 3D model on the monitor; and the very high image resolution makes it possible to see even tiny blood vessels, such as those in and around the heart or in the brain. Computed tomography is especially suitable for visualizing hairline fractures, changes in the organs, tumor search, and heart examinations. It is also used in emergency rooms to rapidly diagnose internal injuries, plan surgical interventions, and check the progress of treatments. A CT scan is completely painless and generally takes less than ten minutes from preparation to the final image.

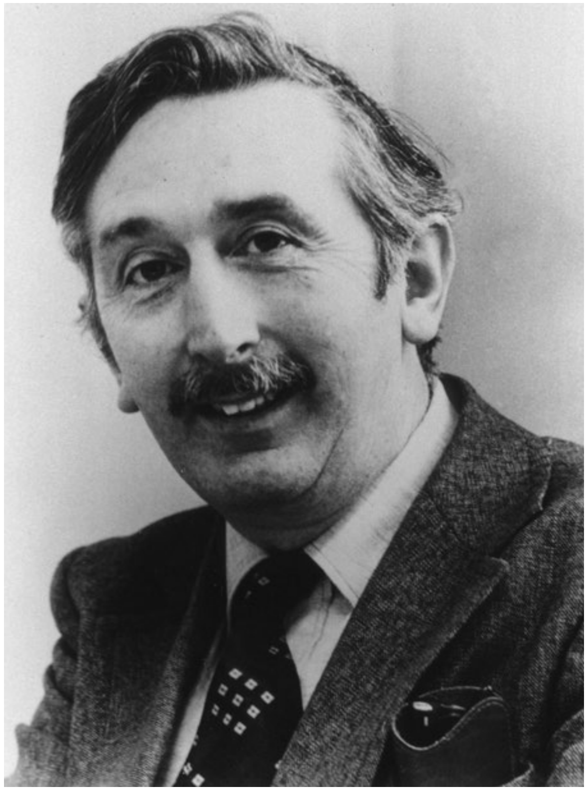


A brief introduction to present-day CT technology

The ring-shaped opening of the CT scanner, which laypeople often call the "donut," is known in the medical community as the gantry. The gantry houses the measurement system, consisting of the X-ray tube and the detector opposite it. The measurement system, which typically weighs between 400 and 1,600 kilograms, circles the patient several times per second. During this process, the tube transmits a fan-shaped X-ray beam, which is weakened less by soft tissue than by firmer tissue as it passes through the body. When they reach the detector, the rays hit a "scintillator" – Siemens uses a highly specialized ceramic mixture – that converts the detected X-rays into light. Photodiodes then convert the light into electricity, and a converter produces digital data from the analog signals and transmits them to the computer for analysis. The computer translates the measurements into individual section images or even a three-dimensional model of the entire body, all without a noticeable delay. The physician can rotate the body image on the monitor, zoom in and out, and even do a virtual "fly-through" to examine structures such as the intestine.

Today's CT systems analyze each patient's physical anatomy and calculate the optimum radiation dose for each scan. Radiation exposure is measured in millisieverts (mSv). Annual exposure to naturally occurring X-ray radiation for a person in Germany averages 2.4 millisieverts. The minimum dose for a lung scan with a present-day CT scanner can be 0.1 mSv. Typical doses range from 2 to 3 mSv.

A gentleman's crazy idea and tremendous enthusiasm at Siemens



Sir Godfrey Hounsfield, the inventor of computed tomography

In London, in fall 1971, a radiologist and an engineer found themselves jumping up and down for joy – as one of them later recalled – "like football players who had just scored a winning goal." In their hands, the two researchers were holding a completely new type of X-ray image – known as a tomogram – that depicted a human brain in unprecedented quality. Indeed, looking at the image, the radiologist, James Ambrose, could see his 41-year-old patient's brain "in a great deal more detail than we'd expected" and could clearly make out the cortex, the spaces filled with cerebrospinal fluid, and even the white matter. The engineer, Godfrey Hounsfield, had developed the new X-ray technology almost single-handedly. With the prototype of his "3D X-ray machine," Hounsfield ushered in the development of computed tomography (CT) – and with it, the era of modern X-ray technology.

"Suppose that certain rays from the sun could penetrate deeply into a pyramid." The history of computed tomography began with a simple thought experiment while Godfrey Hounsfield was out on a ramble with his friend Roger Voles in the mid-1960s. "If we put a detector outside the pyramid on the far side from the sun and move the detector, day-by-day, [...] the whole volume of the pyramid could be explored for undiscovered chambers." This idea stuck with Hounsfield, and soon the pyramid became a box in which he wanted to visualize not only chambers but the entire contents. He realized that scans would have to be taken of the item over 180 degrees in order to collect three-dimensional data. To simplify the calculation of the measured values, Hounsfield planned to divide this three-dimensional data up into several layers, "like putting the object through a bacon slicer." Until 1967, Godfrey Hounsfield's ideas were pure speculation – interesting puzzles born out of scientific curiosity. Then his employer, the electronics and record company EMI, unexpectedly brought his current project to an end.

Legend has it that Godfrey Hounsfield was given free rein to choose his next project and that – when it came to developing the first CT scanner – he could draw upon huge revenue streams that EMI had generated from the success of the Beatles. In fact, quite the opposite was true. In the early days, Hounsfield had to fight for funding for his project, as EMI initially had no ambitions of entering the medical technology market. After several months of persuasion, he earned the confidence of his superiors – although one of them described the idea as "crazy," presumably in the positive sense of the word. In order to build a prototype, Hounsfield was given exactly a quarter of what he requested. With this budget, he performed "miracles with very little money," in the words of William E. Ingham, who was director of research at EMI at the time.

To save money, Godfrey Hounsfield and his small team of developers improvised at every opportunity:

They used an old lathe as the basic framework of the laboratory prototype, and for the data storage device they borrowed a paper-tape punch, which they used to record the measured values on strips of paper, each scan taking the form of 28,800 holes on 60-meter strips. “I have never, before or since,” recalled Stephen Bates, the team’s software engineer, “been involved in any project that took so many shortcuts or utilized so many items of seemingly unsuitable pieces of equipment.” Despite all of the obstacles, the team turned Hounsfield’s ideas into a working scanner in the space of a year. In early 1969, with an exposure time of nine days, they produced the first CT scan in history: an image of some plastic laboratory utensils. Within a few months – using more suitable components thanks to a larger budget from EMI as well as support from the British Department of Health and Social Security – they brought the exposure time down to around nine hours before further reducing it to about five minutes just a few months later.

The first clinical prototype, which the team installed in James Ambrose’s department at Atkinson Morley Hospital in Wimbledon on October 1, 1971, already bore a striking resemblance to modern CT scanners. However, because the system – and the hospital as a whole – lacked a computer to generate the image, the data collected from the first patient’s brain was stored on a magnetic tape and taken by car to an EMI lab about 20 kilometers away. Two days later,

The clinical prototype of the first CT scanner set a new course for the development of X-ray technology as they held the diagnostic image in their hands, Hounsfield and Ambrose found themselves jumping up and down for joy. They began conducting further studies and published their results on April 20, 1972, at a radiology conference in London – triggering the greatest sensation in medical X-ray technology since the discovery of X-rays.

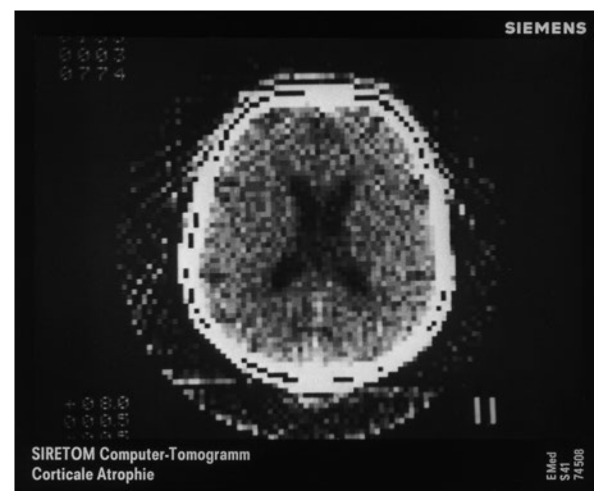
William E. Ingham later recalled that “all doubters in the medical profession and the doubters in the company were all suddenly believers.” Practically from one day to the next, computed tomography set a new course for the development of medical X-ray technology. Godfrey Hounsfield’s invention rendered the technique known as pneumoencephalography, which was common until that point, completely superfluous. In this often very painful and onerous procedure, cerebrospinal fluid was extracted via the lumbar region of the patient’s spine and replaced with air to allow visualization of the brain using X-rays. Pneumoencephalography routinely led to several days of hospitalization and side effects – from vomiting to seizures or even meningitis. With computed tomography, on the other hand, patients could be scanned on an outpatient basis and without experiencing any pain whatsoever – and even the first prototype from EMI delivered much more contrast-rich and accurate results.

These impressive images triggered a veritable epidemic of “CT fever.” Godfrey Hounsfield’s invention and the new kind of X-ray images were the subject of reports not only in medical journals but also in almost all British newspapers and magazines – starting with the Times and then others including the Guardian, the Daily Telegraph, and the BBC. In addition to EMI, a further 17 companies began working on the development of CT scanners. Right from the outset, technical advances in computed tomography came in leaps and bounds. Incredibly, in October 1968, Godfrey Hounsfield had correctly predicted many of the inventions that would follow over the next 40 years – sometimes even down to the technical details, as was the case with the development of multislice CT scanners in 1998. However, some of the major developments from Siemens Healthineers that would shape computed tomography over the years were impossible to predict, as they were based on entirely new approaches – or even on seemingly very peculiar ideas.

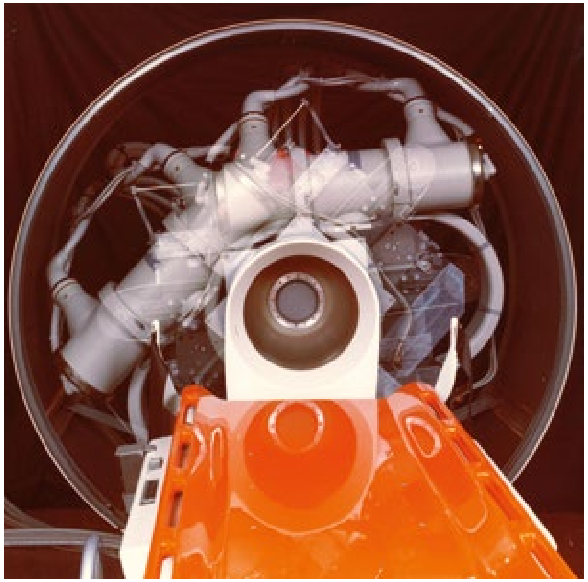
The history of computed tomography at Siemens Healthineers began with a trip to London. The head of development in the medical technology arm at Siemens, Oskar Dünisch, and the head of Siemens X-ray development, Friedrich Gudden, visited EMI’s research laboratory in summer 1972 to discuss the further development of computed tomography. The visit “was highly informative,” Gudden wrote in his memoirs. “Excellent food and Godfrey Hounsfield, the inventor of computed tomography, joined in. He made an excellent impression on me, calm and unpretentious, a real British gentleman. And what he explained was fascinating – for example, that collecting the measurements for an image took nine days at the start.”

The same year, a development department dedicated specifically to CT technology was established in the fundamental research unit at Siemens in Erlangen. The goal was to come up with a powerful prototype optimized for workflows in hospitals and medical practices. The pioneering figures were Friedrich Gudden, Gerhard Linke, Karlheinz Pauli, Benedikt Steinle, and Reiner Liebetruth. Steinle, for example, developed a method of reconstructing images that was later used by all other companies as well, while Liebetruth introduced flicker-free image display on TV screens. The team grew and also received support from other Siemens teams. “Unforgettable” is how Gudden describes “the tremendous enthusiasm of our [...] significantly larger development team.” Work continued every day until late into the night, and Gudden often drove employees who relied on public transit home personally after midnight. The excitement even caught on among employees of DEC, an American computer manufacturer that supplied the computer used for the scanner. Specialists from the service team helped Siemens technicians eliminate defects in the images and “were pleased at the ongoing improvement in the images, as were we.”

One of the first images of the brain taken with the prototype of the SIRETOM CT scanner from Siemens



The prototype of SIRETOM in 1974



The measuring system of SIRETOM, 1974

The control panel of SIRETOM at Goethe University Medical Center in Frankfurt

When they first began this work, the technicians and engineers at Siemens were able to build on their experiences with X-ray technology. Many components had already been developed and simply needed to be adapted to their new purpose. For example, a therapeutic X-ray tube turned out to be particularly suitable for use as a radiation source in the CT scanner. The technicians modified the tube and constructed a high-voltage generator that maintained a particularly stable power supply in order to prevent measurement errors. Other aspects were developed from scratch, including the detector and a new system that converted the computer's calculations into digital images and displayed them on a 44-centimeter monitor. A second screen integrated into the control console allowed the operator to take Polaroid pictures using a built-in camera. Scan results could also be recorded on tape if desired.

As well as refining the basic technology for measurement and imaging, the technicians also turned their attention to seemingly trivial aspects. For example, they built the scanner table so that patients could lie comfortably, which was good news for patients and physicians alike. After all, if the patient was restless and moved during the scan, their movements would produce artifacts in the image – meaning the image would be blurry and hard to interpret. The system was also designed to be as easy and safe as possible for the staff to use. All of the switches needed for a scan were therefore located on a single control desk, and a safety system with automatic locking practically ruled out operating errors.

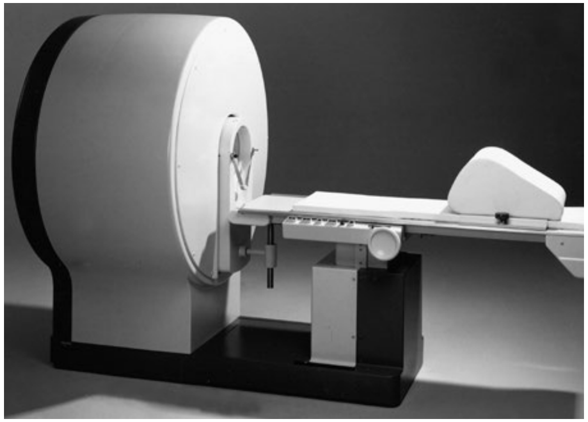
In the first half of 1974, the preliminary work was completed, initial trial runs were possible, and the prototype of the first CT scanner from Siemens had a name: SIRETOM. Even in those days, the cranium scanner could record double slices of the brain using two adjacent detectors. Once the first test images were recorded in the Siemens research laboratory, SIRETOM was to be trialed in clinical settings as soon as possible. To this end, Siemens formed a close partnership with Professor Hans Hacker and his team at the neuroradiology department at Goethe University Medical Center in Frankfurt. The prototype of SIRETOM arrived in Frankfurt on June 19, 1974, and was quickly put into service, performing its first patient scan precisely eight days later.

The system immediately found itself in high demand. By mid-February 1975, it had examined 1,750 patients – which, at an average of four scans per patient, amounted to some 7,000 scans or a total of about 14,000 slice images. The trial was followed with keen interest by many physicians and technicians. Some years later, Friedrich Gudden told of how "legions of visitors were brought to Frankfurt, including competitors, who admired the processing time, convenient use, and image reproduction alike." He also pointed out that the unit was far superior to all others on the market at the time. Nevertheless, it was still the only prototype of its kind and a long way from series production. "If we had been able to deliver at the time, any number of them would have been sold. When American doctors asked about the delivery time and heard our answer, they either laughed or cried, depending on their nature."

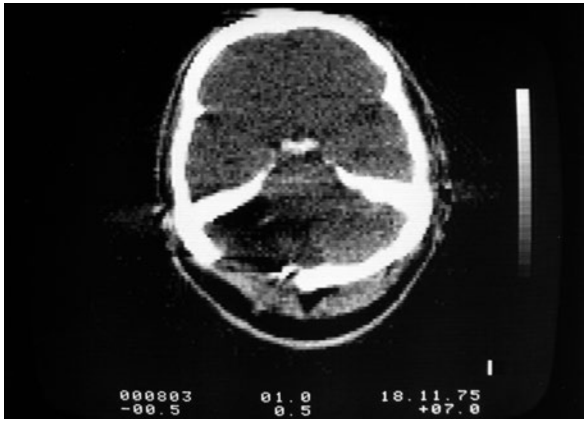
The preproduction model
of SIRETOM in 1975

Hans Hacker was another firm believer in the new technology. In a report, he concluded that computed tomography would be "one of the most important methods used to investigate diseases and disorders of the brain in the future, and SIRETOM can be viewed as a reliable and easy-to-operate system for this kind of scan." With the experience gained in Frankfurt and the findings from other test runs, the Siemens technicians worked on refining SIRETOM and getting it ready for series production. They also increased the resolution from 80 by 80 to 128 by 128 pixels. Over the course of 1975, Siemens presented the scanner to the medical community at the European Congress of Radiology (ECR) in Edinburgh and at the Annual Meeting of the Radiological Society of North America (RSNA) in Chicago. Then, on December 1, the time had finally come: Professor Hacker's prototype was dismantled, and he was the first to receive a series-produced model of the Siemens SIRETOM cranium scanner.

The presentation of SIRETOM at the
ECR in Edinburgh, 1975



Series-produced model of the SIRETOM, the first Siemens CT scanner, 1975



A head scan using a series-produced model, 1975

New insights into the brain

The SIRETOM cranium scanner passed the clinical validation tests performed in 1975. The system was already being used at several university medical centers to perform neurological scans, for example where there was a suspicion of brain disease or to plan an operation. SIRETOM proved especially useful in trauma care. It allowed physicians to quickly identify and locate possible brain injuries without placing additional strain on the patient. This was a major step forward at the time: Conventional X-ray images of the head showed bleeding or tumors barely, if at all, since the bones of the skull overlay the soft tissue of the brain, causing an overshadowing effect. The process required laborious, time-consuming preparations that were uncomfortable for patients. The only way to see the vessels of the brain using the methods commonly available back then was by administering contrast agents, and visualizing the chambers of the brain required the displacement of cerebrospinal fluid with air. Patients generally needed to spend several days in the hospital following the lengthy procedure.

Computed tomography was significantly simpler, faster, and less invasive even as far back as 1975. It was also considerably more accurate than any other method previously used to examine the brain. With SIRETOM, patients could be scanned on an outpatient basis and completely without pain. The system depicted tumors, cysts, hemorrhages, and even tiny areas of calcification without contrast media. A SIRETOM scan took 30 minutes at most, including positioning the patient; and scanning a double slice itself was completed in just four to five minutes. During the examination, a fine X-ray beam scanned the brain, point by point. The detector located opposite the beam registered several hundred values and forwarded them to the computer. After every scan, the SIRETOM unit turned the X-ray tube and detector by one degree. After an additional 179 turns, the system had measured two neighboring slices, each one centimeter thick. If necessary, four double slices could be scanned, providing a picture of the entire brain. The computer processed the measurements so quickly that the doctor could call up the resulting image just two seconds after the final measurement was taken. A life-size image of the brain was then shown onscreen and could be printed as a Polaroid picture or stored on tape as desired.

From head to toe

The technology was ready to be launched on the market, and the medical community was impressed by the new possibilities. Within just a short time, computed tomography became the preferred method for examining the tissue of the brain. The high-contrast images sparked a logical desire among many physicians: They wanted overlay-free CT images of the entire body so that they could examine areas such as the liver, intestines, and joints. Even before work on SIRETOM was completed, Siemens began studying the technical fundamentals that would be needed for whole-body CT scans. The engineers faced two main problems: The gantry needed to be much larger, and the scan time had to be shorter. Shorter scan times were necessary because patient movements, such as breathing, would cause artifacts, which led to images that were blurry and difficult to interpret, if the scan time was too long. This meant that image quality depended on scan time, and so CT developers in the mid-1970s began working to reduce the time from just under five minutes to 20 seconds instead. In many cases, this would make it possible to produce images during a pause in the patient's breathing.

The SIRETOM scanning method had mechanical limitations that meant that the scan time could not be shortened to any meaningful degree. A new technology had to be developed to accelerate the entire measurement system. The time-consuming, detailed process of scanning used by SIRETOM, with the measurement system turning by one degree after every step and then performing another scan, was replaced by a system that rotated 360 degrees around the patient in a single pass. This was made possible by a special tube and a new configuration: A fan beam X-ray tube generated a broad fan of X-rays covering the entire patient. Instead of a single detector element, the opposite side of the unit now housed a larger arc-shaped detection device with numerous individual detectors to capture the entire fan-shaped beam. This structure was a major challenge to the engineers: The components weighed several hundred kilograms and built up a huge amount of centrifugal force during the rapid rotation, yet the system also had to be designed to run extremely quietly and smoothly.

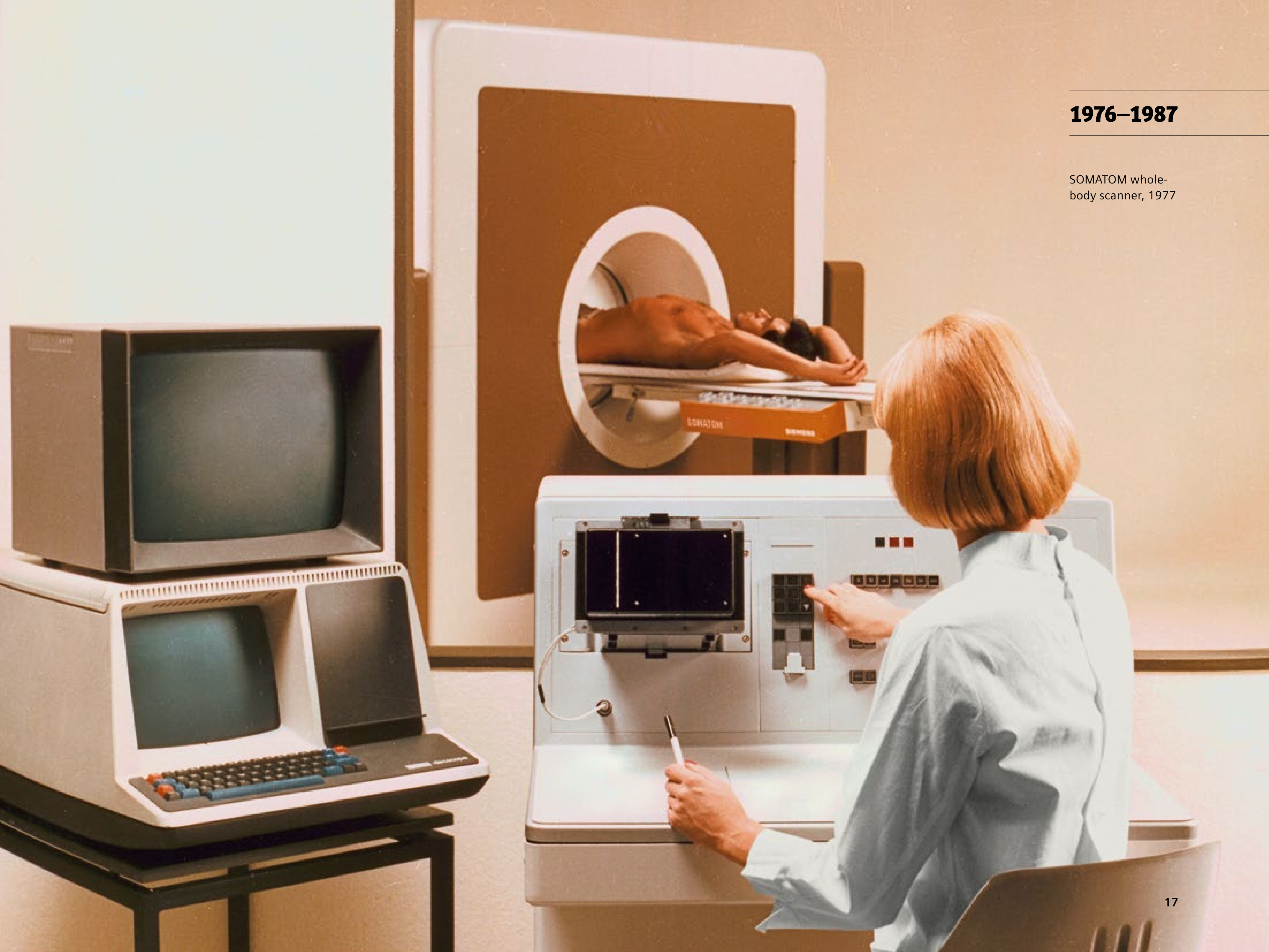
SIRETOM 2000 head scanner, 1977

SOMATOM abdominal scan image produced without contrast media, 1977

After a three-year development period, Siemens presented its SOMATOM whole-body CT system in September 1977. The system was even faster than the 20-second target that the engineers had set for themselves: In normal operation, it could scan a slice either eight or four millimeters thick in just four seconds. In quick scan mode, in which only the data from two-thirds of a revolution were collected and used to reconstruct an image, the unit needed just 2.5 seconds per section. The detector system consisted of 256 discrete measurement elements. On each rotation, SOMATOM collected more than 92,000 measurements, which were converted by a computer and immediately presented on a monitor as a grayscale image. For archiving purposes, scan results could be photographed or stored on videotape or magnetic disks.

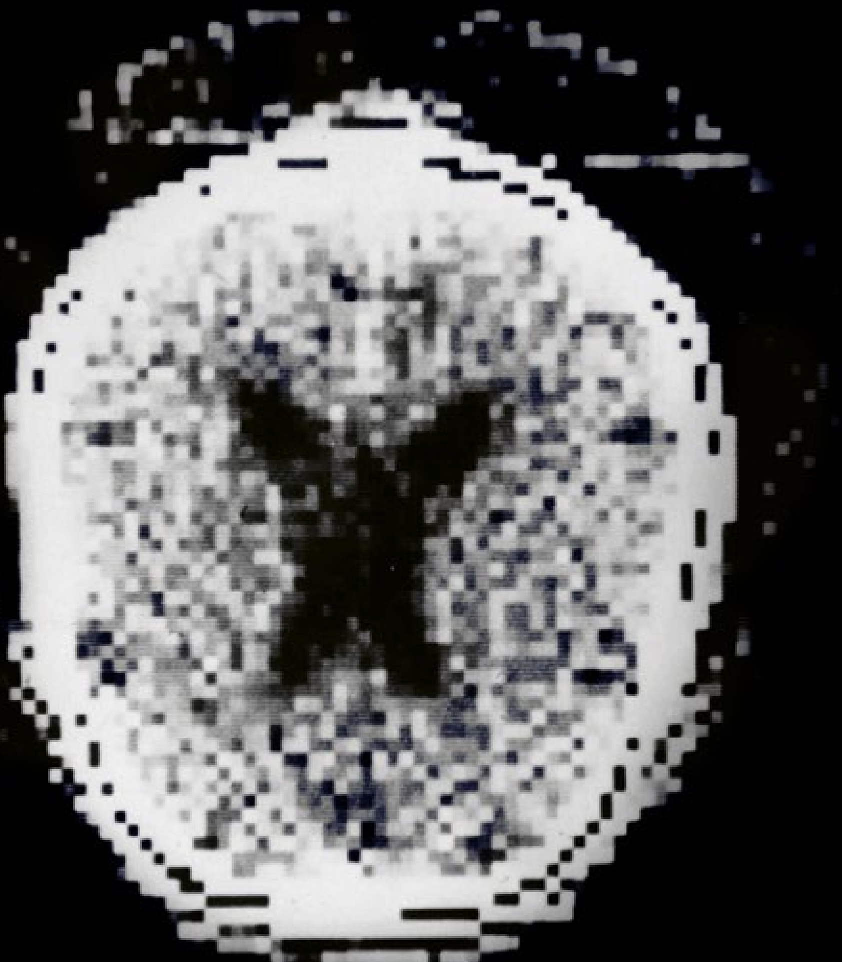
The SIRETOM gantry opening was 23.5 centimeters across, while the SOMATOM opening measured 54 centimeters. The patient was positioned on a remote-controlled conveyor and moved into the opening for the scan. A light-beam localizer helped position the patient optimally. Before the scan, the physician selected a measurement program for the various types of tissue in order to adjust settings such as the Standardization accordingly. With these adjustments, the first SOMATOM unit could visualize various parts of the body, including the kidneys, abdominal aorta, and numerous details of the musculature, without the need for contrast media. However, the system was still much too slow to produce sharp images of the beating heart.

1976–1987



SOMATOM whole-body scanner, 1977

1974



1983

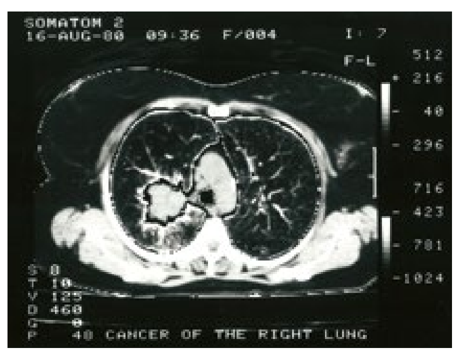
Computed tomography was advancing rapidly. Shortly after SOMATOM system was introduced, Siemens presented an improved version of its SIRETOM head scanner. SIRETOM 2000 performed significantly better and was easier to use than its predecessor. Instead of an image matrix of 128 x 128, SIRETOM 2000 had 256 x 256 pixels, so it offered four times higher resolution per image. And even with the considerable gains that had been made in image quality, the engineers had also markedly reduced the scanning time. What had taken five minutes with the previous model now took just 60 seconds . This was a long time compared to the SOMATOM, but it made no difference for scans of the brain and neck, since these areas of the body are not subject to fuzzy images as a result of patient movements. Patients and medical staff benefited from the revised configuration of SIRETOM 2000. Low gantry depth and free access from the back made preparations easier and more convenient, and the 29-centimeter opening made it more comfortable for patients since they had more room and a clearer view. This made the system a much better fit, particularly for small children and in emergencies.

For the new SOMATOM produced in 1979, Siemens refined the detector system, an especially important element in terms of image quality. With 512 detectors instead of the previous 256, the SOMATOM 2 system now offered twice the spatial resolution. During a scan, there were now twice as many measurements to be processed – 368,640 instead of 184,230. To keep the scan time from also doubling, the engineers developed a faster processor. The duration increased slightly, from four to five seconds in normal operation and from 2.5 to three seconds in quick scan mode, but the advantages of the new configuration more than outweighed this. For example, it was now possible, to visualize the beating heart using a cardio CT addition. This was achieved using a method called "triggering": An ECG measured the heart function and synchronized the SOMATOM 2 with the patient's heartbeat. The unit then emitted an X-ray pulse only at certain points in the cardiac cycle, meaning that it did not measure the heart when it was pumping, but during the brief resting phases in between. This kept the CT image largely free of disruptions caused by the movement of the heart.

The two images of the brain on page 16 show how quickly computed tomography developed within a decade. The image on the left was produced in 1974, while the one on the right was taken with the current SOMATOM model in 1983. While a doctor can already identify and localize tumors or hemorrhages in the older image, details of the brain and the optic nerves are clearly visible ten years later. Such detailed images involve a huge volume of data, i.e., the measurements that need to be calculated and converted by the computer. So that it could deliver an immediate image even before the scan had finished, SOMATOM was equipped with what was then the fastest mass-produced image processor in the world. It could perform about 25,000,000 calculations per second. In 2015, any smartphone is much faster than that, but this processing speed was highly impressive back in 1983.

Also impressive were the weight and dimensions of a new CT unit introduced by Siemens in 1984. It weighed approximately 25 tons and was about 15 meters long. The new unit was a semi-trailer truck housing an entire CT department, with a radiation-protected, air-conditioned examining room, interpretation room, and technical section. This CT unit on wheels offered numerous advantages. In rural areas, where there are fewer patients, operating a stationary CT unit can often be prohibitively costly. With the SOMATOM trucks, several small hospitals or medical practices could share the investment costs and allow their patients to undergo CT scans. The mobile CT technology also helped large medical centers that occasionally needed to perform more scans than usual. Operating these kinds of systems is more expensive and laborious, and they face challenges such as inclement weather and poor transportation routes.

Preparing for a scan with the SOMATOM 2, 1979



Lung cancer image, 1980

A full CT system in a semi-trailer truck, 1984

A scan performed with the SOMATOM DR, 1984

SOMATOM DR with accessories, 1984

Osteoporosis check, 1986

Checking the functionality of SOMATOM DR, 1986

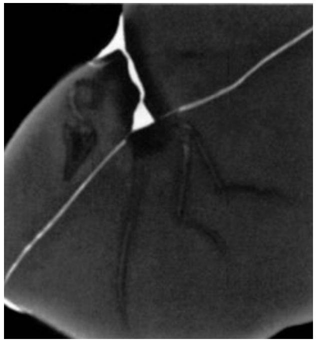
Still, the SOMATOM unit in a trailer or bus met the same quality standards as a stationary system. More than 15 SOMATOM systems literally hit the road in the spring of 1984, with plans to boost that number to around 30 by the end of the year. The engineers also had smaller hospitals and radiologists in private practice in mind when planning the SOMATOM DR 1 entry-level model. As a result, the major goals for the development of this system were to achieve low purchase and operating costs and minimal space needs without compromising on quality and comfort. This was achieved by heavily revising the system components. For example, a new and significantly smaller X-ray generator made it possible to install an entire CT unit in less than 40 square meters of space. The high-performance X-ray tube could absorb more heat and cooled off faster, so it could be operated with a less extensive cooling system. SOMATOM DR 1 was part of the new SOMATOM DR family and could easily be retooled or expanded as needed, using components from other models to adjust it to different tasks.

Another "family member" underwent a detailed comparison at the same time. At the 1984 RSNA, American physicist Thomas Payne, of the independent institution Midwest Radiation Consultants, Inc., in St. Paul, Minnesota, presented the results of his tests of state-of-the-art CT systems from various manufacturers. Payne used special measurement phantoms to compare detail resolution and artifacts in the CT image. The Siemens SOMATOM DRH, a high-end model with 704 detector elements, performed the best in all the measurements. The images from the Siemens system offered the highest geometric resolution, displayed the fewest image artifacts, and were also superior to images produced by competing devices in the posterior cranial fossa, an area especially prone to artifacts.

By the mid-1980s, CT images had become so detailed and expressive that scientists from fields outside of medicine had begun to use the technology for their research as well. Egyptologists, cultural historians, and anthropologists were interested in ancient Egyptian mummies, a rich trove of information on their living conditions, and other aspects of their times. Computed tomography was able to bring the insides of these mummies to light without damaging their valuable exteriors. This allowed researchers to identify things like changes in the skeleton and teeth and see signs of operations performed during life-time and possible causes of death. This kind of CT scan would previously have been impossible because the gantry was too small, but the 70-centimeter gantry of most of the new SOMATOM models from 1984 onward could accommodate even a large, bulky sarcophagus. This wider opening not only made it possible to scan 4,000-year-old mummies, but in radiological practice it also meant added comfort and convenience for doctors – and above all, for overweight and obese patients.

Another of the many interesting examples of the use of computed tomography in research concerns an animal even older than any mummy. The field of paleo-ornithology, which studies fossilized birds, faced a hotly debated question at the time: Could an archaeopteryx fly, or not? About 145 million years after the pigeon-sized archosaur died out, CT images taken with a Siemens SOMATOM system provided new impetus for the debate without damaging the few fossilized specimens that had been found.

In 1987, computed tomography had reached the point where scanner performance could hardly be enhanced



CT scan of an archaeopteryx, 1986

at all anymore – at least not with the basic technical framework that had been used so far. The main limiting factors were the supply of energy to the gantry and the transmission of measurement data from the gantry to the image processor. At this stage, X-ray tube and detector system were connected to the power supply via cables. This meant that the gantry could not rotate continuously, but instead had to be accelerated in one direction, stopped after a 360-degree rotation, and then accelerated in the opposite direction. To further reduce scan times and thus improve image quality, engineers went to work on a wide range of solutions in the 1980s. The technology that would ultimately catch on is still used for the power supply in most CT scanners today: Instead of cords, the rotating components are supplied with electricity via slip rings. These allow the gantry to rotate continuously and collect data without interruption.

Slip ring technology accelerated the entire scanning process and also laid the foundation for one of the most important innovations in the history of computed tomography. We'll come back to that later. First, let's take a look at what was then the fastest CT scanner ever: Siemens SOMATOM Plus.

A cast of Archaeopteryx siemensii, donated to the Berlin Museum für Naturkunde by Werner von Siemens in 1880

1987

The measurement system of the SOMATOM Plus, ca. 1988

Abdominal scan, 1988

Rendering of space requirements for the SOMATOM Plus, 1988

Changing times

In the first ten years after the launch of SOMATOM, there were no changes in the fundamental technology used for CT scanners. Engineers expanded the possible applications, improved the components, and thus pushed the existing technical framework to its limit. One key aspect of that limit was the way the measurement system, which weighed several hundred kilograms, worked. Acceleration, 360-degree rotation, deceleration, stop, rotation in the other direction, stop – with umpteen repetitions per scan, an extreme level of mechanical strain with no further room for improvement. Shortening scan times further, a crucial point in achieving better image quality, would only be possible if the measurement system could rotate continuously.

In late 1987, Siemens shortened the time needed for a 360-degree scan with the world's first fully rotating – and thus fastest – CT system to just one second. SOMATOM Plus was the first unit in a new CT generation. Continuous rotation was made possible primarily by a new kind of energy supply. Up until then, the gantry had received its electricity via cables, but now the energy was transmitted using slip rings. The entire measurement system ran on a newly developed bearing designed for continuous high-speed rotation. In addition to the higher system speed, this technology had the advantage that operation was significantly quieter and involved less wear than with the previous start-stop method.

Significantly higher speed also meant significantly larger data volumes. To transmit the information, Siemens used an optoelectronic system, which converted the electronic data from the measurement system into light and transmitting it in that form.

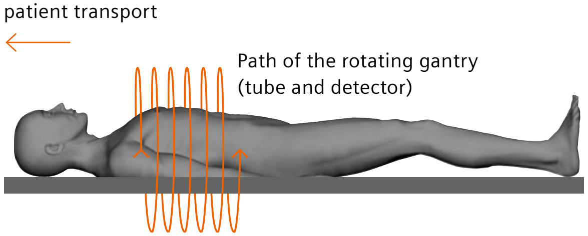
The other components of SOMATOM Plus were adapted to exploit the potential offered by the higher system speed. The DURA X-ray tube had twice the power of previous tubes and cooled down considerably faster. This made it possible to take more than 100 individual images in a twelve-second scan, all without pausing. A technology known as MULTIFAN scanned the patient's tissue from different angles, making it possible to visualize the most detailed structures of the bones and soft tissue in a single image.

With SOMATOM Plus, Siemens strengthened its leadership in the CT market. It secured a technological lead over competitors for several years and laid the foundation for the next revolution foundation in high-power systems: Spiral CT.

A seemingly very peculiar idea

How much can power and quality in computed tomography still be improved? Is there a fixed limit? And if so, can that limit be transcended with a new approach? These and similar questions were increasingly making the rounds among specialists in the mid-1980s. In fact, computed tomography was reaching the point at which major gains were no longer possible with the existing technology. With slip rings, and the continuous rotation these enabled in SOMATOM Plus, Siemens overcame this barrier and laid the groundwork for one of the biggest innovations in the history of computed tomography: Spiral CT.

Spiral-CT



At first, the idea behind this sounded quite peculiar indeed, since spiral CT does exactly what engineers and designers had been trying to avoid in computed tomography until then: It moves the patient inside the scanner. Conventional CT systems work sequentially. This means that the tube and detector circle the patient while the table stays in a fixed position and produce a scan of one slice of the patient's body. After each scan sequence, the table moves a few millimeters along the body's longitudinal axis, and then the scan of the next section is produced. If the patient moves during the scan, the measurement data are no longer consistent. This leads to motion artifacts, which can even render the image unusable for diagnostic purposes in extreme cases. The basic idea behind spiral CT is to move the patient table through the measurement field continuously in order to access the benefits of even faster scanning. The X-rays then scan the body in a spiral path. The medical community's response to this suggestion was skeptical at first. Critics even called spiral CT "a method of producing artifacts in CT."

Yet spiral CT promised a huge leap in performance if the issue of blurring caused by movement could be resolved. Various researchers working independently of each other and – as is often the case with new scientific methods – without knowledge of each other's work developed the initial concepts and conducted experiments. Many of them scrapped the idea at first, however, or saw it as merely a theory without practical benefit. At Siemens, a team headed by physicist Willi A. Kalender started researching spiral CT in 1988. About a year later, the group presented physical tests and clinical studies of the method's performance. The solution to the problem of motion artifacts lay in mathematics. Complicated algorithms needed to be added to the software used for reconstructing the images in order to factor the movement of the table into the measurements. The other components were largely similar to those of conventional systems, but they needed to be adapted to the specific requirements of spiral CT. Some of them needed significantly more power, and controlling the processes within the system was much more complicated.

Later that year, Kalender and his team built the first spiral CT prototype. However, the technical limitations that applied in 1989 were still too extensive for the system to be used in clinical settings. A year later, after substantial experimentation and clinical tests, the time had finally come: Siemens launched SOMATOM Plus-S. The world's first spiral volume scanner. A "volume scan" is an image of an entire area of the body, such as a whole organ. In equential scans, offset images can result: Movements between the individual sectional scans, such as the natural contraction of the intestines or breathing, lead to individual slices being positioned differently. If these individual images are then lined up with each other, they can be so far out of alignment that, in extreme cases, the final result shows double slices or even incomplete ones. Through spiral scanning, SOMATOM Plus-S set new standards in volume imaging. It could scan a volume of as much as 30 centimeters within 30 seconds in a single pass, without any gaps. With spiral CT, the movements happening inside the patient's body were no longer an issue.

1989–1998

SOMATOM Plus-S, the world's first spiral CT system, 1991

The 3000th SOMATOM leaves the test facility, 1991

Control and analysis console, 1989

Bone mineral content determination via spiral CT, 1991

The level of detail in the images produced by SOMATOM Plus-S was so high that it was even possible to determine the mineral content of a patient's bones. This meant that the system could be used with the OSTEO CT software to diagnose and monitor the progression of osteoporosis. SOMATOM Plus-S automatically located the contours of the vertebrae, determined the slices to be scanned, and then presented the results in a clearly laid out, easy-to-understand diagram. The crucial factor in this process was that users could reproduce scans accurately to show the progress of the disease during regular check-ups.

It was already clear in 1990 that the future belonged to spiral CT. Still, for more than two years SOMATOM Plus-S remained the only system on the market to use this scanning technique. The other major CT manufacturers announced their own systems using slip ring and spiral technology at the RSNA in the fall of 1992. At that time, many experts assumed that spiral CT would only be used in high-end systems in the future, too. This forecast later turned out to be mistaken, but a few more years would pass before the first spiral CT system for the lower segments of the market was presented.

If you look closely at the pictures of the control and analysis console, you can see the user interface. The monitor on the left shows a result image, and on the right, the operator controls the scan using special commands. One command, such as "TOMO/2/20/120/50," sets parameters such as the slice thickness, X-ray power, and number of slices. From today's standpoint, this approach seems very old-fashioned. However, it was easy to learn, so customers accepted it for a long time, especially since the entry options were expanded to include an electric pen that converted writing into graphics – truly state-of-the-art technology at the time.

Other features of the CT systems available around 1990 also seem antiquated today. Installing the systems required significantly more work back then, so it was also more time-consuming. Merely setting up the mechanical parts of the gantry took a technician several days. Replacing parts was also complicated and sometimes required two service technicians. Computed tomography units needed much more energy and more space – at least 36 square meters. They were also very sensitive to electromagnetic pulses. If an error occurred in the system, the screen would merely show a cryptic number without further explanation.

Siemens launched its "Project 47" with the goal of significantly improving these and other points. A team composed of former ultrasound engineers and "old" CT engineers was tasked with developing an unprecedented CT system: A system that could be installed within two days and would require no more than 20 square meters of space, was operated by a user interface like that of a PC and a computer mouse, cost just one-third of the price of previous entry-level models, and required significantly less energy. The final product of Project 47 was an extremely unusual CT system: SOMATOM AR. In technical terms, this entry-level system featured quite a few major new developments. The unusual thing about it was that new developments are normally introduced from the top down, meaning that they are developed for high-end systems and gradually move down to the systems in lower price segments. The project goals that had been achieved were joined by additional new system components that had been developed from the ground up.

The communication interface between the six microprocessors was so powerful, for example, that it became the standard for medical technology from Siemens. Today, interfaces like this one can be found in any CT system, and in many other electronic devices and in all cars. SOMATOM AR was also the first system with pre-produced wiring instead of the wire harnesses that had been customary until then. This dramatically reduced the possible sources of error.

At about 170 centimeters in height and width, SOMATOM AR seems very small compared to other CT systems. The compact design was made possible by various factors, including what developer Andres Sommer called a "fairly ingenious design of the tilt bases." For the first time, the entire tilt mechanism was contained within the unit casing. However, it almost didn't come to that, as a funny story from the development department shows: "When we had set up the unit for the first time and used the tilt, a very heavy colleague, about 160 kilograms, was lying on the table," Sommer recalls. "As the tilt increased, he was squeezed more and more in the 60-centimeter opening. We were all stumped as to whether we should build the system that way." The team worked on other tasks for a time, but the subject of tilting eventually returned to the agenda and the heavy colleague was back in the gantry as a test subject. The engineers were astonished to see that there were suddenly "no problems at all with the tilt. Everything was fine, and everyone was happy. What we hadn't noticed was that our colleague had lost 30 kilograms in the meantime, so he met the requirements for the table."

SOMATOM AR, 1994

SOMATOM Plus4, 1994

SOMATOM AR arrived in 1991. It was aimed at customers who wanted to shift from a conventional X-ray system to CT. To ensure that it was also available to customers in more remote areas, such as in Africa or India, the entire system was designed to be transported with just one truck. Even more importantly, SOMATOM AR needed so little energy that a standard electrical outlet was enough to supply it with power. The system was a complete success. Siemens produced almost three times more SOMATOM AR units than planned. Over the years, new models in the AR family were launched after being upgraded with new technologies and adapted to the various markets. In 1994, Siemens presented SOMATOM AR.SP with spiral CT. Two years later, the AR family was reissued in a fresh, contemporary design. The technology inside stayed the same, since it had proven to be highly reliable; Nearly a quarter-century later, in 2014, Siemens employees discovered a SOMATOM AR built in 1992 in China, still running perfectly and scanning 15 to 20 patients per day.

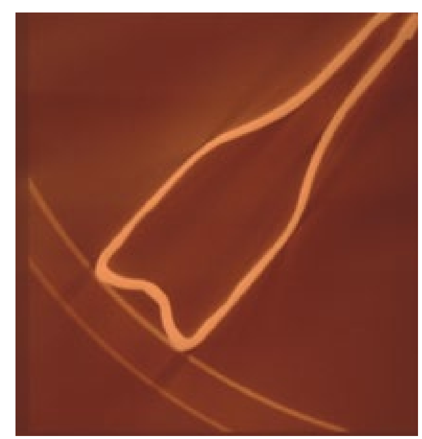
On October 22, 1993, the CT engineers at Siemens were looking forward to a bottle of sparkling wine. It was scanned as the first test image to be produced with SOMATOM Plus4 and then drunk to celebrate the success. When the system was launched on the market, in 1995, it was the fastest CT scanner in the world – which, oddly enough, no one noticed at first. SOMATOM Plus4, completed a rotation in 0.75 seconds, while all other scanners at the time needed at least a second. Siemens built on the insights gleaned through Project 47 when developing the new unit. By that time, the software was so advanced that all the doctor had to do was select the desired examination and the system would perform all of the necessary scans and sequences automatically. SOMATOM Plus4 already had numerous options, but another 51 were added over its five-year lifetime. These included perfusion CT, to visualize circulation in the organs, and tracking programs that automatically position the patient correctly and then perform the scan.

With SOMATOM Plus4, the engineers found that they had a “luxury problem”: The high-performance components delivered 300 images or more per slice scan when used with spiral CT. That was too many to use diagnostically with the methods then available. New solutions were needed in order to evaluate and visualize datasets faster. These efforts had various results, including the possibility of displaying scan images in three dimensions – also a function unique to SOMATOM Plus4 at the time.

In 1997, another innovation premiered in SOMATOM Plus4: A “solid-state detector” with a special material used to convert X-rays. First, though, let’s take a look at how the detectors had worked up until then. The xenon detector, the first generation of CT detectors, worked using the noble gas xenon. The gas was held under high pressure inside a measuring chamber. When X-rays struck the detector, they changed the state of the gas molecules, exciting them and causing them to lose electrons through the energy transmitted by the X-rays, in a process known as ionization. This generated electrical impulses that were registered in the chamber by measuring electrodes and then forwarded for data processing. However, a xenon detector only absorbs 60 to 90 percent of the incoming X-rays and converts them into usable signals.

At the detector center in the Franconian city of Forchheim, Siemens developed a special ceramic mixture that absorbs almost all X-ray radiation and converts it without any loss. UFCs (ultra fast ceramics) replaced xenon gas as the material used in the detector. The ceramic absorbs the rays and converts them directly into photons – visible light. UFCs are not only significantly more efficient than xenon, but also offer a much shorter afterglow period. A shorter afterglow means that the material becomes “dark” again faster and can absorb new X-rays, that is new information. This represented a huge step in X-ray technology, since from then on, radiation doses could be reduced by as much as 30 percent without affecting image quality. Today, UFCs from Siemens Healthcare are also used by other industries, including. Automotive manufacturers, for instance, use them to examine materials non-invasively, and the furniture industry uses them to determine the quality of wood.

Of especial importance in the field of medicine – and thus also in medical imaging – is accurate, dependable scans of the heart, since this is where the root cause of many physical problems lies. Siemens has been working on various approaches to further improve cardiac imaging for a long time. One unusual approach was a tomography system that featured unique technology: Electron beam tomography (EBT) was originally developed by Imatron, a company in San Francisco with which

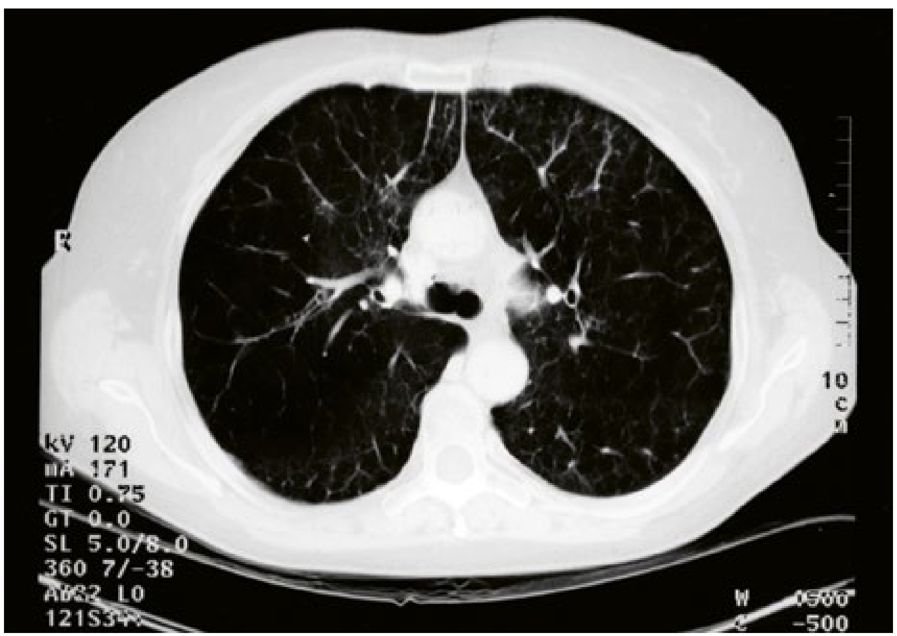


A bottle of sparkling wine as a test image, 1993

Siemens worked in the 1990s. Unlike in conventional CT systems, in which the X-ray tube assembly and detector system rotated around the patient, the gantry of an EBT scanner did not contain any moving mechanical parts. The X-rays were generated in a three-meter-long vacuum tube behind the gantry. Electrons moving at high speed struck anode ring segments arranged in a semicircle in the lower part of the gantry, where they generated the X-rays that struck the detector semicircle in the upper part of the gantry.

The advantage of EBT technology is its extremely rapid scanning time. At just 50 milliseconds per slice, it was perfect for cardiac CT. Yet the method also had serious disadvantages, especially when it came to visualizing other areas of the body. The quality of the images was not even close to that of images produced by conventional CT scanners and further development activities also did not promise any significant improvements. With this in mind, Siemens decided in the mid-1990s to halt development of electron beam tomography and focus its resources on other approaches – which will be explained in more detail in the rest of this section.

After the innovations of the previous ten years, there was no comparison between early systems and the diagnostic quality and user and patient friendliness offered by the new units. Along with the SOMATOM Plus and SOMATOM AR product families, Siemens offered numerous other systems tailored to the various needs of its customers. One example is the Miyabi Angio-CT system, a combination of a full angiography workstation and a CT system that slides on rails. Many limits had been overcome, but in the mid-1990s, the engineers were faced with a new one: The power of X-ray tubes could not keep being increased without affecting the tube lifespan. However, there was a way to put the existing power to better use while also making a huge leap in cardiac CT: Multislice CT.



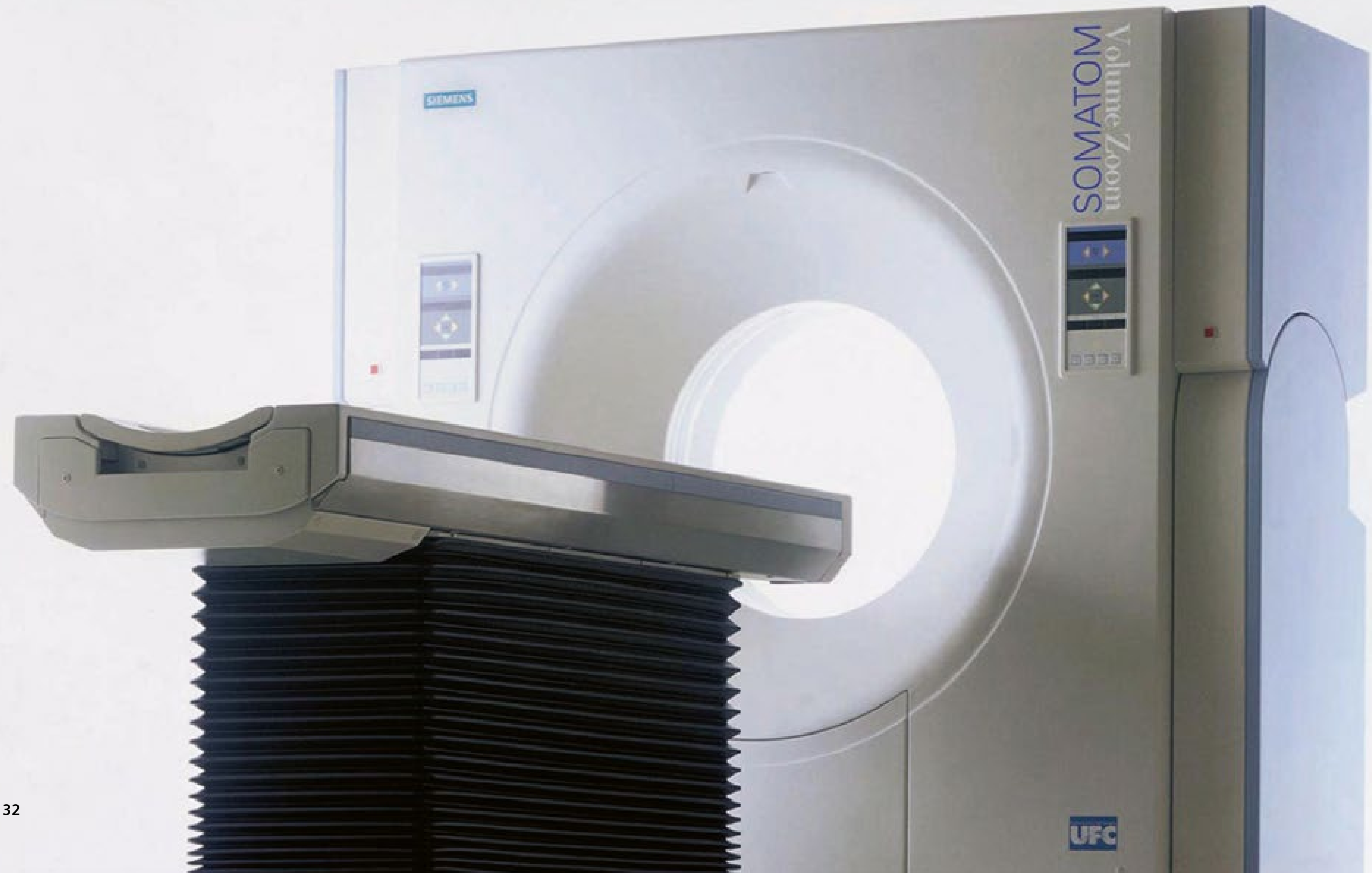
An image of the lungs produced with SOMATOM Plus4, 1997

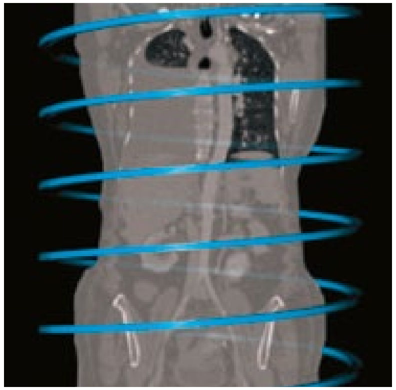

Miyabi Angio-CT, 1998

The UFC detector for SOMATOM Plus4, 1997

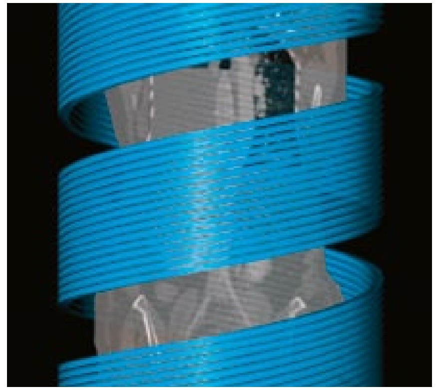
1998

A paradigm shift in computed tomography

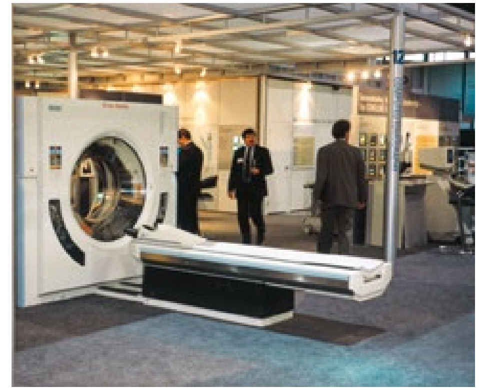




Single-slice spiral CT



Multislice spiral CT



Presentation at the RSNA, 1998

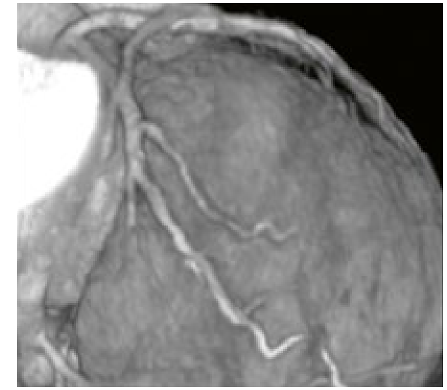


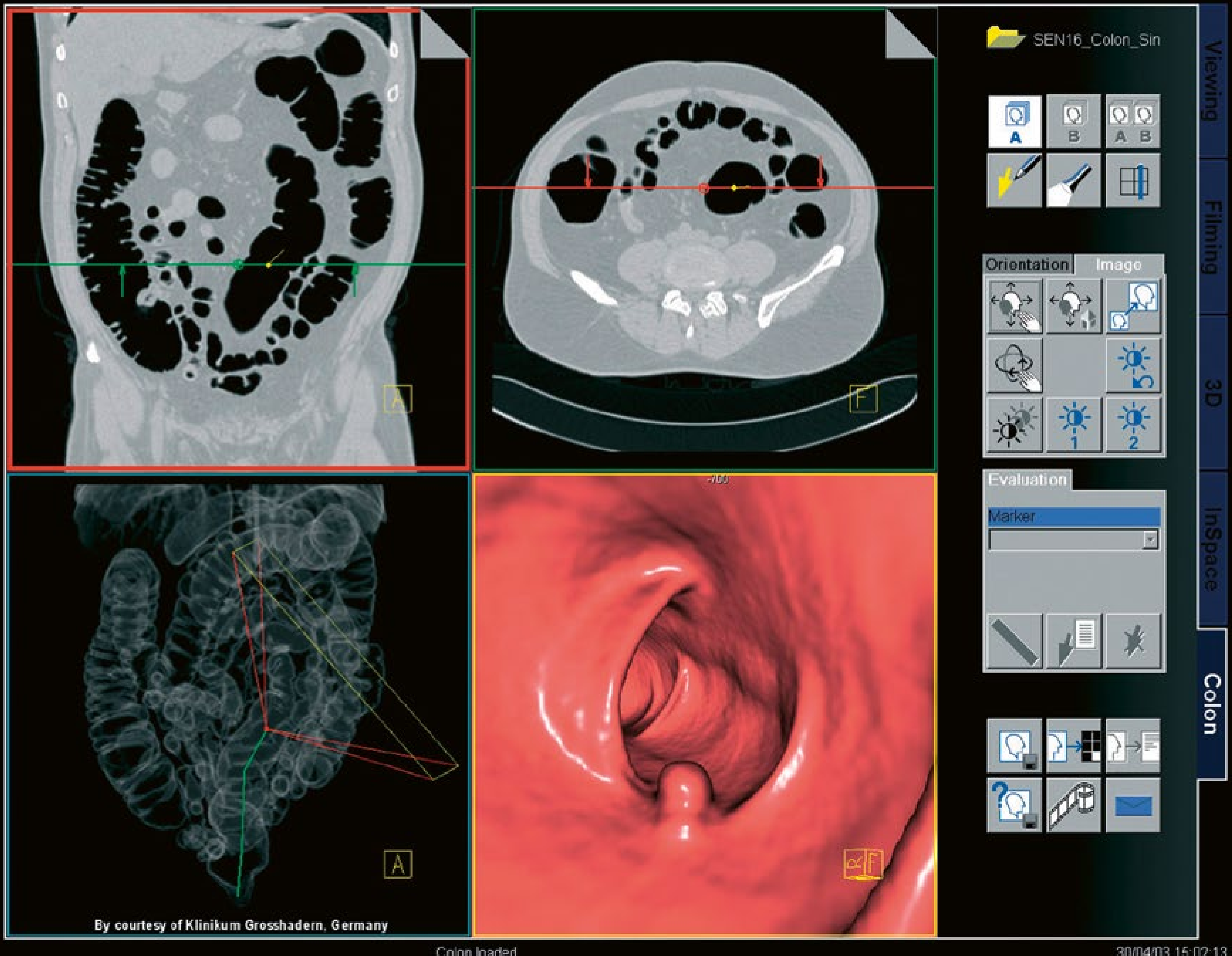
Image of coronary arteries at Klinikum Grosshadern, Munich, 1999

Up until this point, physicians had to decide between volume size and sharp detail: Was it necessary to visualize the entire organ, or would it be enough to produce images of thin slices, but at a higher resolution? With SOMATOM Volume Zoom, the question became moot. This was due to two factors. First, the rotation time was just 0.5 seconds per rotation. Second – and more importantly – the machine featured the new multislice technology. Conventional detectors scan one slice per revolution. In multislice technology, the photodiode is spread among the detector elements on separate rows that process the signals transmitted by the X-ray tube independently of each other, thereby recording several slices per rotation – four in the case of SOMATOM Volume Zoom. This multiple-row detector utilizes the X-ray output significantly more efficiently, enables image resolution that is up to eight times higher in a longitudinal direction relative to the patient, and considerably reduces scan times for large areas of the body. Siemens achieved this high resolution by arranging the individual slices in a certain way. In an "adaptive array detector," the slices are very narrow, widening toward the outer edges. Because variable settings are available for the X-ray tube collimator, resolutions of between 0.5 and 5 millimeters per slice can be selected, producing much thinner slices than before.

For Siemens, the main goal in developing multislice CT technology was to further reduce scan times and further enlarge the possible scan volume. Yet SOMATOM Volume Zoom was a milestone in many ways, representing a paradigm shift in computed tomography. Up until then, vascular examinations had been performed invasively, generally using catheters. Multislice technology ushered in the era of routine vascular imaging using CT scanners. It also brought a fundamental shift in how scan results were viewed: As the slices were much thinner, significantly larger volume datasets were now available. This meant that it became less and less common to visualize individual slices, and the grand era of threedimensional imaging began. SOMATOM Volume Zoom was also the first unit to have an automatic operating concept. Before then, users had to think about the right scan parameters before every scan, but now the SureView software handled this aspect, determining the optimum settings for the scanner. SOMATOM Volume Zoom marked an especially important point in the history of cardiac CT. The first CT image of the coronary vessels was produced at the Klinikum Grosshadern facility, Munich, in 1999. It took about 40 seconds, but Siemens recognized that there was further potential. It began devoting great efforts to pushing development forward in cooperation with clinical partners. Over the next few years, this would turn out to be a major contribution to the field of cardiac imaging – without Siemens, there would probably be no such thing as routine cardiac CT today.

1998–2005

Three-dimensional image 32 of the interior walls of the intestine in *syngo*, 2003



Small dose, big progress

In the 1970s, computed tomography was a revolution. In the 1980s, there was still something special, something exclusive, about it. By the early 1990s, it had become a matter of course, an established technology and a crucial part of everyday clinical practice. Entry-level models put CT within reach even for hospitals and radiology practices with smaller budgets. Several major innovative leaps, especially continuous rotation and spiral CT, improved image quality and significantly expanded the range of applications. On the eve of the new millennium, the dose per scan was just a fraction of the X-ray power that was needed in older CT scanners. This was due to two factors: Significantly more efficient hardware, such as the UFC detector, and software specially developed for this purpose, such as "combined applications to reduce exposure" (CARE). Among other things, CARE technology calculated the smallest possible dose that would deliver the best possible image quality for each patient. Depending on the patient's anatomy, CARE could reduce the radiation dose by as much as 56 percent.

Siemens unveiled another groundbreaking software innovation in 1999. With *syngo*, the company became the first manufacturer of medical technology to craft a standardized user interface for all of its systems. CT scanners, magnetic resonance imaging (MRI) systems and other imaging systems from the same manufacturer had previously used different software interfaces – and operators had to learn how to use each of them separately. *syngo* allowed Siemens to standardize the way its equipment was operated. When a hospital or medical practice purchases a new system from Siemens, the learning curve for staff is much shorter. The graphical user interface consists entirely of simple, self-explanatory symbols. Behind the *syngo* interface are numerous functions that have been optimized for workflows in clinical settings and medical practices. For example, all of the data on a patient can be compiled in the electronic patient file, so the physician can always keep track of past scans and tests, including CT findings, lab results, and operative reports. Cross-department networking accelerates workflows, allowing doctors to focus more on patients. Siemens, too, benefits directly from *syngo*. The interface makes integrating new developments into the existing system much easier. In February 2000, the company received the iF Interaction Design Award from the international judging panel of Industrie Forum Design Hannover for *syngo*. The jury's statement: "In short, the epitome of a user interface, which is already clear from the fact that work steps and connections were readily apparent even to us as laypeople without background knowledge of the subject."

Ultra-fast, smooth medical care is a must in hospital emergency rooms. These are where initial care for patients with serious injuries or trauma starts. Doctors there maintain the patient's vital functions and diagnose the injuries or the physical cause of the emergency. CT is excellently suited to providing rapid diagnoses. Yet at this point, doctors still had to move CT patients from the operating table to the CT table and then, at most hospitals, from the trauma room to the scanner room. The optimum solution for emergency rooms would be if the patient could lie on a freestanding operating table and the CT scanner could be moved to the patient. With this in mind, Siemens developed the "sliding gantry" – a SOMATOM on rails – in 1998. In the new system, the first of its kind in the world, the patient lay

SOMATOM Plus4 CARE ad, 1994

Preparing for a scan in a trauma room, 2001 completely still on the table and received all of the necessary care from medical staff without any space restrictions. If necessary, a fully functional SOMATOM Plus4 could be moved into the scanning position in less than one minute. The system could also be combined optionally with the Siemens MULTISTAR Plus angiography C-arm and various ultrasound diagnostic systems.

PRIMATOM, 1999

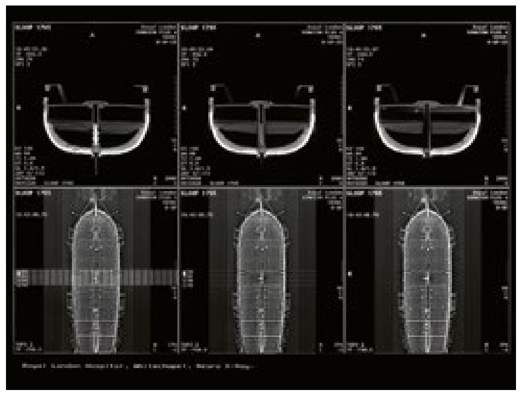


Image of model ships, 1999

Not long after the development of the SOMATOM Plus4 sliding gantry, Siemens received an inquiry from James Wong, Chair of the Department of Radiation Oncology at Morristown Memorial Hospital in Morristown, New Jersey. Wong was using linear accelerators to fight cancer. A linear accelerator is a radiation treatment device that accelerates electrons almost to the speed of light and beams them at cancer cells. Up until 1999, radiation therapy had involved "flying blind." This meant that when treatment plans were drawn up, the tumor's position was determined once and it was assumed that it was always in the same location, even if the patient was positioned slightly various during different treatment sessions. A simple detector was used to check the location of the bones, but it was usually not possible to see the tumor in the process. On top of that, organs tend to move inside the body. These factors meant that radiation fields were expanded, in some cases significantly, in order to be sure that all of the tumor cells were targeted. What Wong wanted to do was check the tumor's position with a combination of a linear accelerator and CT scanner before every radiation treatment.

The team headed by engineer Andres Sommer at Siemens in Erlangen began looking for solutions to the mechanical issues and concluded that "this kind of solution was easy to build". They relied on the principle of the sliding gantry to develop PRIMATOM, the world's first 3D image-guided radiation therapy system. The team installed this cross between a CT scanner and a linear accelerator in Morristown in April 1999. Several months later, Sommer visited the site for a closer look at the workflows involved. He discovered that analyzing and interpreting the images and resetting the system for the next patient took a very long time. It just so happened that, the team in Erlangen was working on developing the first version of an image reconstruction software program based on *syngo* at the time. Specifically for PRIMATOM, they added a new software function that showed the necessary shifting of the patient in 3D images. The visit had been worthwhile. The system now worked ten times faster than before.

In addition to significantly greater accuracy, PRIMATOM also brought other advantages to radiation therapy, including this one: "Integrating imaging into therapy unlocks a new dimension for us in treating cancer patients, namely the ability to consider how the tumor changes over time during the course of treatment," as Jürgen Debus, MD, a professor and Medical Director of Clinical Radiology at Heidelberg University Hospital, said in 2004. At the time, more than 500 patients had been treated with the first PRIMATOM in Europe, which was being operated at the German Cancer Research Center (DKFZ) in cooperation with the University of Heidelberg. PRIMATOM with *syngo* and the additional software function represented a milestone in radiation therapy. It is still recognized as the gold standard for image-guided systems to this day.

In the fall of 1999, CT at Siemens entered uncharted territory. The UK National Maritime Museum in London, the Royal London Hospital, and the medical technology arm at Siemens teamed up to learn more about the craftsmanship of British shipbuilders in the 17th and 18th centuries. Endoscopic scans performed in the past had yielded only modest insight, and so the plan now was to use a CT scanner to generate cross-sectional images of the ships. Since the 70-centimeter gantry of a SOMATOM Plus4 was a bit too small for a life-size sailing ship, the researchers scanned model ships which British carpenters had built at the time to serve as exact prototypes for shipbuilding. The engineers at Siemens adjusted the image processing algorithms to accommodate the particular characteristics of the materials used in the ships. Naturally, the research took place in the evening so that it would not impede routine operations at the hospital. The length of the gantry is irrelevant when scanning model ships – but when dealing with patients, it's a different story. Some people feel cramped inside the "tube," and some get an uneasy feeling just looking at it. This means that one important goal for any development in this area of medical technology is to boost patient comfort and make the scan as pleasant as possible. As a result, the new SOMATOM models launched in 1999, Emotion and Balance, featured a gantry that was just 56 centimeters long. At that time, it was the shortest on the market. The compact design not only made the scan easier for many patients, but also benefited operators, who had better access to the patient. For these and other aspects of their design, such as improved service and easy maintenance, SOMATOM Emotion and SOMATOM Balance received the iF Product Design Award in 2000.

SOMATOM Emotion,
2001

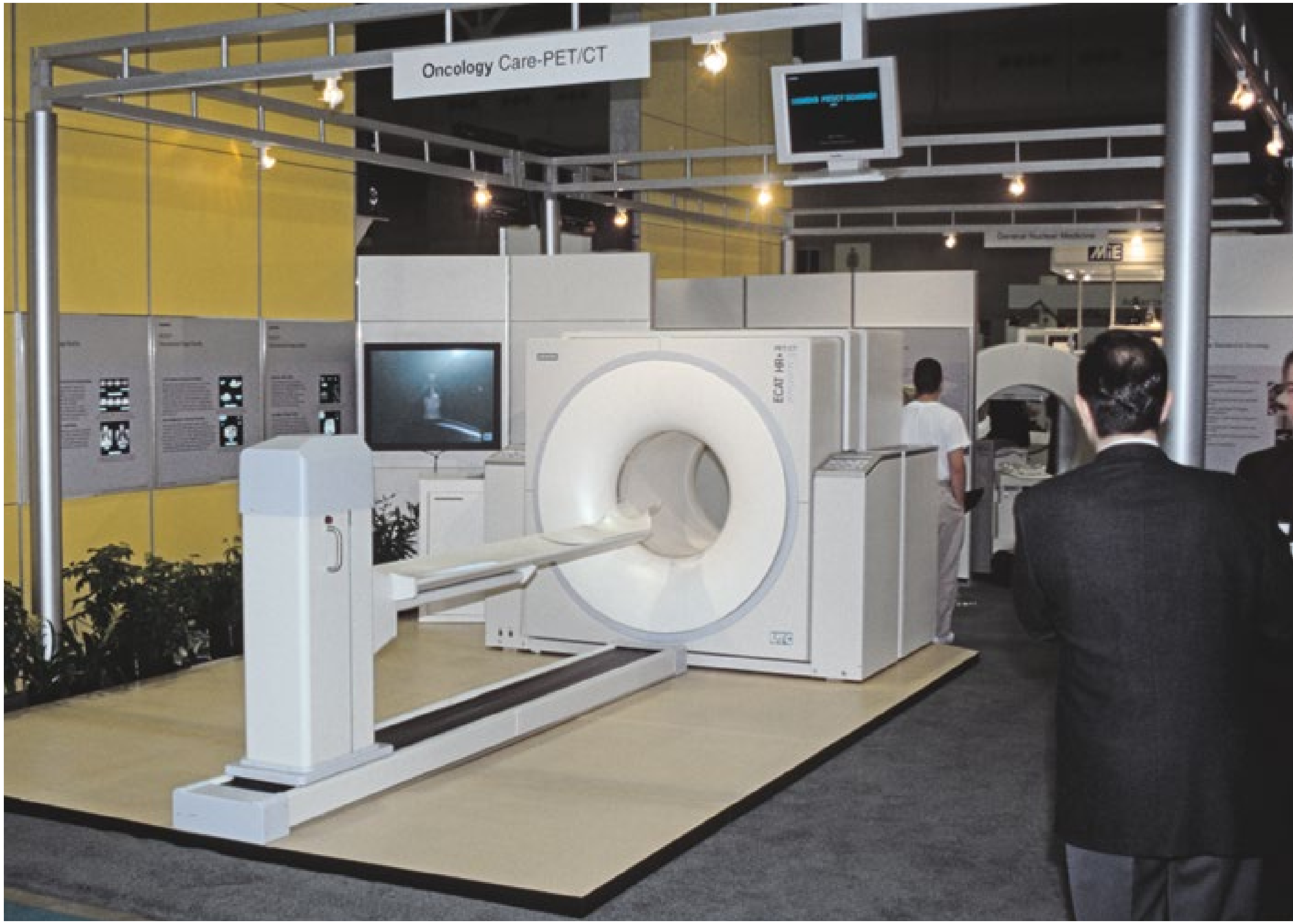
SPECT-CT Symbia, 2004

A few weeks after the awards ceremony, Siemens launched SOMATOM Esprit. The new model also had a gantry just 56 centi-meters long, but it was also even more compact overall. The entry-level SOMATOM Esprit did not have an additional cooling system, which meant that it needed just 17 square meters of space. The system also came equipped with features otherwise found only in larger CT scanners. The standard features included a UFC detector and spiral CT. Functions such as CT angiography or CARE Bolus, a program to reduce the need for contrast agents, could also be added upon request. The system could be installed and ready for the first scan in just one day.

The computer used for CT systems is based on microprocessors, just like in a cell phone or PC. In 1965, Gordon Moore, one of the co-founders of Intel, observed a correlation in the development of electronic components that, in a slightly modified form, still applies to microprocessors to this day: "Moore's law" holds that the power of micro-processors doubles every 24 months. This means that if a hospital buys a CT scanner today, that same system, equipped with a new microprocessor, would work even faster in a few years, and it would even be possible to add new functions and applications. For customers who wanted to keep their system up-to-date, Siemens began offering its Evolve service package, later marketed under the name *syngo* Evolve Package, for all imaging systems. The SOMATOM Volume Zoom and Volume Access systems installed between August 1999 and October 2000 were the first to benefit from this program, receiving hardware that was four times faster in July 2002. The package included the *syngo* VA40 software upgrade, which brought various features with it, including new applications for pediatrics and cardiology. Customers also had the option to add new functions to their systems, such as the ability to do a virtual "fly-through" of a patient's intestine. Users could adjust the scope of the service package to suit their individual needs. More than 75 percent of all customers purchasing a new SOMATOM in 2002 opted for a service package.

Each of the established imaging methods has its own strengths, that make it especially suitable for certain types of scans. Ultrasound is the first choice for many routine examinations, such as for preventive care during pregnancy. Magnetic resonance imaging (MRI) delivers extremely sharp, detailed images of areas of soft tissue such as the brain. Computed tomography offers razor-sharp images of the skeleton and precise results when time is of the essence, such as when a stroke is suspected. Two other important methods used for clinical imaging are positron emission tomography (PET) and single-photon emission computed tomo-graphy (SPECT). These nuclear medicine methods can be used to obtain a detailed picture of bodily functions and metabolic processes. They are primarily used to diagnose and treat cancer, heart disease and neurological disorders. Since they are geared specifically toward biochemical processes, PET and SPECT have limited use in visualizing the anatomical details of the body. In many scans, however, simultaneously visualizing metabolic processes and anatomical structures with accuracy down to the sub-millimeter level is crucial for optimum treatment planning – for example, being able to determine quickly and accurately where and to what extent a patient's heart muscle has sustained damage due to an inadequate blood supply after a heart attack. Up until then, this kind of diagnostic procedure required two separate scans – one with a PET or SPECT scanner and one with CT – and then the resulting images were superimposed over each other. This method was time-consuming; it meant a lot of work for medical staff and was also cumbersome for patients.

Hybrid systems could combine the particular strengths of these nuclear medicine methods with those of CT in order to detect certain diseases and disorders faster, earlier, and with greater reliability. The same idea had also occurred to David Townsend of the University of Pittsburgh and Ron Nutt of CTI PET Systems, Knoxville, Tennessee, which was a joint venture between Siemens and CTI. They applied for a patent on the idea of combining PET and CT technology, and planned to build the first hybrid system with support from the CT team at Siemens. To this end, Siemens sent a SOMATOM AR with spiral CT capability from Forchheim to Pittsburgh in 1997. Thomas Beyer, then a research associate at the university, built a prototype there by combining SOMATOM AR system with a PET system from Knoxville. The first scans, performed on more than 300 cancer patients, showed impressive results. Building on this, a Siemens team was tasked with preparing the combination system for the market. They produced a special CT scanner based on SOMATOM Emotion, sent it to Knoxville, and built a combined PET/CT scanner there, launching it on the market in 2001 as the Siemens Biograph. The path they had taken – opening up the possibility of producing simultaneous CT and PET images – soon turned out to have been the right one. In about five years, individual PET scanners were no longer being sold. The Biograph was built in nine versions, with multislice technology and numerous new functions and improvements.



Presenting the first PET/CT combination scanner at the RSNA, 2000

In the early 2000s, Siemens began considering whether it would be possible to build a SPECT/CT hybrid without lowering quality standards, and if so, how. A team of engineers working in nuclear medicine and computed tomography planned the unusual architecture, decided on SOMATOM Emotion as the CT component of the system, and combined it with the latest SPECT technology, the e.cam. Siemens presented the results of this development, the TruePoint SPECT- CT, in mid-2004, and named the new product family Symbia. The system was extremely versatile. In addition to combined SPECT/CT scans, Symbia systems could also be used for either SPECT or CT scanning, depending on the clinical needs. The engineers' decision to use SOMATOM Emotion turned out to be just right. SOMATOM Emotion is still on the market to this day, and upgrades and improvements for this scanner can be imported seamlessly into the Symbia family.

In December 2001, a mere three years after computed tomography had first been used to visualize the coronary arteries, Siemens took the next step by introducing the world's first 16-slice multislice CT scanner. SOMATOM Sensation 16 now made even the surrounding segments of the coronary arteries and their delicate side branches visible. The leap from four to 16 slices and the even faster rotation time – just 0.4 seconds – brought numerous advantages. For example, it now took only about ten seconds to perform a lung scan. Yet there was one area where SOMATOM Sensation 16 really excelled: Cardiac imaging in conjunction with the "HeartView CT" software. This program allowed doctors to see areas of narrowing and deposits in the coronary arteries, a hugely important factor for early detection in particular. For their work on HeartView CT, the development team headed by Bernd Ohnesorge and Thomas Flohr was nominated for the 2002 Deutscher Zukunftspreis, the highest award for innovation in science and technology given in Germany. That same year, the Design Award of the Federal Republic of Germany went to the CT development unit at Siemens in recognition of a very special system: SOMATOM Smile.

An entry-level model, SOMATOM Smile was designed for private radiology practices and smaller medical facilities in China, Southeast Asia, and Brazil. The system was simply plugged into a normal electrical outlet and was ready to go in just three hours. If technical problems occurred, an intelligent self-test function helped to identify the malfunctioning or defective parts and then displayed the correct order number onscreen. Customers could order the replacement component from Siemens and replace it themselves based on convenient color-coding. The concept used to operate the system was also revolutionary: The unit came with a CD-ROM containing training software that taught users – step by step and in clear, easily understood terms – how to use all of the system's functions. It covered everything, from turning on the scanner to patient positioning and preparing images that could be used for diagnosis. For its ease of use, appealing design, and intelligent overall concept, SOMATOM Smile won the Design Award of the Federal Republic of Germany, the 2001 red dot award, and the 2002 iF Design Award.

SOMATOM Smile, 2000

A conventional CT tube versus Straton, 2005

Computed tomography places an immense strain on the X-ray tube, especially in the case of spiral CT and the high speeds that come with it. Before the introduction of spiral CT, tubes had worked according to the following principle: The airless X-ray tube contained a cathode and a rotating anode that were linked to each other through the application of high voltage. The cathode was heated up, causing it to discharge electrons. The electrons were accelerated and collided with the anode. This generated X-ray radiation, which was then beamed out of the tube. The weak points of this design are the heat and the position of the rotating anode. The longer a CT scan lasts, the hotter the anode gets. It is cooled by discharging the heat through the vacuum to the cooling oil surrounding the tube. This cooling process is not very efficient, and forces users to include pauses so that the system can cool down between scans. Two major design changes significantly boosted X-ray tube performance: Pivot bearings outside the tube for greater stability, and direct cooling of the anode.

Back in 1993, Willi A. Kalender and Wolfgang Knüpfer started working at Siemens on what they called a rotating envelope tube, an approach later continued by a team of developers headed by Peter Schardt and Erich Hell. In this design, the entire vacuum tube rotates instead of just the anode. This makes the mechanical construct significantly more robust and compact, yielding further benefits. The most important factor is the direct cooling of the anode: Compared with conventional CT tubes, the rotating envelope tube discharges about ten times more heat. The rapid cooling allowed the engineers to install anodes that were significantly smaller and thus also weighed less. This further enhanced mechanical stability and made it possible to achieve even greater rotation speeds. Another prominent new development lay in the details: The "z-spring focus" recorded every projection from two to four different perspectives during the scan, significantly improving image clarity. In 2003, Siemens presented this unique development to the public as the Straton® X-ray tube – an innovation that brought the team headed by Peter Schardt and Erich Hell a nomination for the Deutscher Zukunftspreis award for innovation in science and technology in 2005.

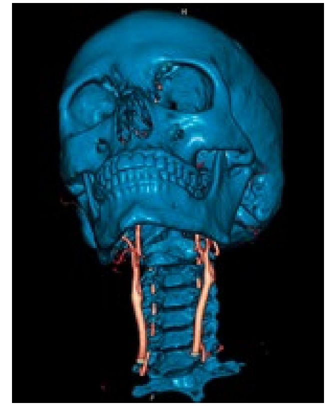
The ability to bring CT systems fully up to date without completely redesigning the underlying framework was a major goal for the engineers with each development. The SOMATOM Sensation family is a good example of the benefits of this approach. In 2001, SOMATOM Sensation 16 was the world's first system with a 16-slice detector. Using z-spring focus technology, the Siemens engineers quadrupled the number of slices that could be scanned at once. When it was introduced in 2003, SOMATOM Sensation 64 became the world's first 64-slice CT system. The engineers were also able to optimize scanners within a system family to meet specific requirements. Siemens launched SOMATOM Sensation Cardiac 64, a system specifically optimized for cardiovascular imaging, in 2004. The rotation time was faster than the base system: 0.33 seconds to the base system's 0.37. It also came pre-installed with additional hardware and software designed specifically for cardiac scans. SOMATOM Sensation Open made it easier to scan overweight and obese patients. It built on SOMATOM Sensation 16, but featured upgrades including an 82-centimeter gantry and a Straton tube. This shows that technological evolution – with all the innovations, improvements, and new application options that come with it, increasingly boosts performance across a system family over the years. A technological revolution generally depends on fully redesigning the basic framework and then introducing the new design in a new system family – just like with the next groundbreaking CT system from Siemens: SOMATOM Definition, the first Dual Source CT scanner.

SOMATOM Sensation 16, 2002

Heart scan with
SOMATOM Sensation
Cardiac 64, 2004

Trial run with dummy, 2006

Gantry production, 2006



The skull and cervical spine of a 59-year-old man, 2006

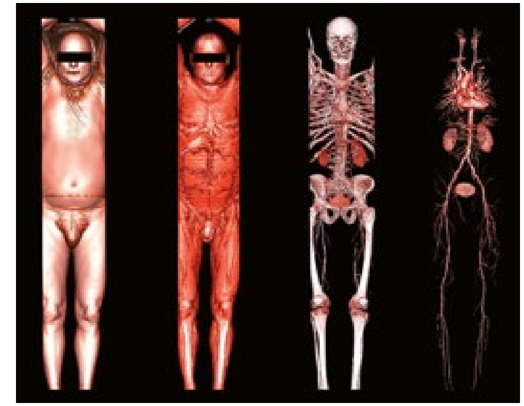


Image of different levels of the body in the same man, 2006

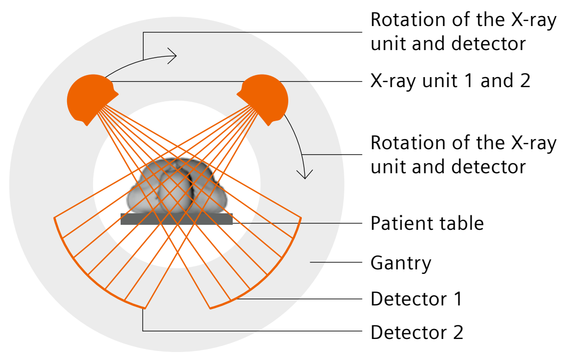
Twice the scanning power

With spiral CT, the UFC multiple-row detector, the Straton tube, and other hardware and software innovations, computed tomography in the mid-2000s made it possible to produce images of inside the body at levels of detail that would have been unimaginable not long before then. Siemens then took the next major step by coming up with a simple but ingenious idea that doubled the power of scans in the high-end segment while also cutting radiation doses almost in half: SOMATOM Definition was the first system in the world to have two X-ray tubes and two detectors rotating around the patient.

The main reason for the development of this technology, known as Dual Source CT (DSCT), was cardiac imaging. SOMATOM Definition set completely new standards for scan speed, image resolution, and the temporal resolution of images, an especially important factor in cardiac CT. Before then, patients with a high heart rate had to take beta blockers to lower their resting heart rate before undergoing a scan. With Dual Source CT, for the first time the scanner was now fast enough to eliminate the need for these drugs. The reason for this lay in the scanning procedure: A CT scanner with one X-ray tube and one detector collects data during a 180-degree path around the gantry, but SOMATOM Definition with dual source technology only needs to rotate 90 degrees to do the same.Combined with a gantry rotation time of just 0.33 seconds, this brought the time needed for a full scan of the beating heart down to only 0.083 seconds – twice as fast as before.

It might seem paradoxical at first that the radiation dose required with two X-ray tubes is significantly lower than with one, but there is a simple explanation: With two tubes, completing a scan takes half as much time. Whether the patient is large or small, fat or thin, is unimportant. With the two Straton tubes, SOMATOM Definition has more than enough power reserves to scan even very obese patients without any ill effects on image quality. For certain scans, the two tubes can also be operated with “dual energy,” meaning at different tube voltages. With low energy, the radiation is attenuated differently in the body than with high energy. This technique can be used to produce two datasets containing different information in a single scan. This has obvious benefits for a field like emergency diagnostics, for example: One tube can be optimized to visualize bones, while the other can be set specifically for imaging soft tissue or fluids.

2005



Operating principle of Dual Source CT

2005–2014

Improved detail for major impact

The long chain of individual technical improvements that scientists and engineers all over the world have worked on has made computed tomography an essential tool for everyday clinical use over the years. Comparing older images with those produced today paints an especially vivid picture of how far this technology has come, but the figures are also impressive in their own right: Back in the 1970s, the first CT systems took about five minutes to scan one slice. By 1980, this had been reduced to between four and ten seconds. Ten years later, it was just one or two seconds. The fastest scanners in 2005 needed just 0.33 seconds to do the same. Advances in CT technology are similarly apparent if we look at the volume of data collected for each 360-degree rotation. This rose from less than 0.06 megabytes (MB) in a prototype from 1972 to 1 MB in the early 1980s, 2 MB in 1990, and as much as 100 MB in 2005. Each spiral scan produced in 1990 generated between 24 and 48 megabytes of data, while a scanner from 2005 collected up to 4,000 MB in just a few seconds. Over the years, innovations from Siemens have repeatedly brought fresh energy to the field of computed tomography. They have driven advances in whole new directions and set trends in many cases.

syngo WebSpace, 2006

The latest Siemens development in 2005, Dual Source CT, sounds like a simple idea: Just install a second tube, and a a second detector, and there you have it – a dual source scanner. In reality, the technical side of implementing this idea was a huge challenge for the engineers, because the gantry was already very tightly packed in conventional systems with single source CT. Without the compact Straton X-ray tube, Dual Source CT would not have been, at least not without changing the structure and making the scanner significantly larger. Yet the new tube technology alone was not enough to make the leap. The engineers had to optimize almost all the other components and make them more compact. This included the entire cooling system and the way that the electronics were arranged in the gantry. Precisely this task – developing even more powerful, more efficient components – would keep the engineers busy over the years to come, as well.

It all started with the optimization of SOMATOM Emotion, which had become one of the most commercially successful CT scanners in the world since the first model was launched. The new model introduced in 2005 turned the system from a low-cost, entry-level model with a single-slice detector into a low-cost, entry-level model with a 16-slice detector. The fully overhauled system retained all of the strengths of its predecessor, including the small installation space of just 18 square meters and low power consumption, but it also offered numerous new functions. The new unit had an internet connection, adding flexibility for operators. Optional *syngo* WebSpace software allowed doctors to access and work with scan results in encrypted form via the internet. The Guardian™ service program was installed to monitor the scanner's functions online and flag any abnormalities before disruptions could arise.

A similar system from the SOMATOM Emotion family helped clear up a suspected murder. The question of whether famed pharaoh Tutankhamun had been killed by a blow to the head more than 3,000 years ago was a source of considerable debate among Egyptologists. In January 2005, Egyptian researchers cracked the case with help from a SOMATOM Emotion 6.

The bust of Nefertiti, 2007

The hidden portrait becomes visible, 2007

The 1,700 tomographic images taken of the mummy showed no signs of murder; instead, the results pointed to the effects of a hunting accident. The CT images also showed that Tutankhamun was between 18 and 20 at the time of his death, not between 23 and 27, as some Egyptologists had estimated. As part of the research project, the Egyptian Council of Antiquities scanned numerous other mummies and historical finds, some of them about 5,000 years old. The SOMATOM Emotion 6 was loaded on to a tractor-trailer and driven to wherever it was needed. This meant that the delicate ancient Egyptian remains were hardly moved at all, and thus treated as carefully as possible.

A bust of the Egyptian ruler Nefertiti had already been scanned using CT technology back in 1992, a process that yielded a startling secret: Inside the sculpture, there was a second portrait of Nefertiti in limestone that looked different from the outer depiction. CT had made such tremendous advances since the time of this first scan that the hidden portrait could now be shown in full detail. With this in mind, the National Geographic Channel decided to re-scan the queen in 2007 for a TV documentary, with help from Siemens. The new scan image, produced with a SOMATOM Sensation 64 and showing structures as tiny as 0.3 millimeters, even reveals clear lines around the mouth. The nose is less harmonious, the shoulders stocky and asymmetrical. Nefertiti seems older and less characteristic. The researchers suspect that the limestone core inside the bust is closer to the queen’s real image than the plaster exterior. Solving archaeological mysteries was an exciting and interesting sideline, but computed tomography was naturally geared mainly toward use in medicine. In the mid-2000s, the technology was so accurate and advanced that it was hard to imagine there was any further room for improvement. Nontheless, work on technical details, patient comfort, and user-friendliness would continue over the next few years and bring astonishing further progress and new developments. At that time, Siemens started developing various features, including a new generation of detectors, and optimized the hardware and software used for the product families.

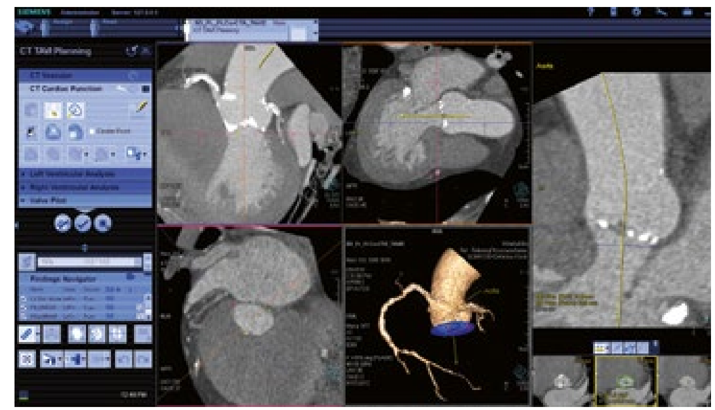
Siemens introduced a number of single source systems with flexible configuration options to join its top-of-the-line SOMATOM Definition model with Dual Source CT technology. In 2007, the high-end system with one X-ray tube was SOMATOM Definition AS. The “AS” stands for “adaptive scanner,” meaning that the system adjusts to all patients and medical requirements. The Siemens engineers achieved this flexibility by combining components such as a 78-centimeter gantry and a scan length of up to 200 centimeters for the first time in this system. This made SOMATOM Definition AS suitable for a wide range of patient groups, such as overweight people, those with claustrophobia, or children. It could also perform complex neurology or cardiology scans with no restrictions, and fast scans in emergency situations, such as trauma, stroke, or heart attack patients. These kinds of emergency examinations were also the main area of use for the very first SOMATOM Definition AS, which was installed at the trauma center at Erlangen University Hospital in late 2007.

CT systems from Siemens are not only flexible once they are already in clinical use; their adaptability is present even before purchase. All of the current systems offered by the company at that time can be configured by customers according to their requirements. From the number of detector rows to software and service packages, numerous options are available. The systems can be upgraded with new hardware and software innovations as required in the years to come. This was true of both pure CT systems in the SOMATOM family and hybrid systems like the Miyabi, Symbia, and Biograph mCT families. In 2008, all of these systems were equipped with multislice detectors, and the Biograph mCT and many SOMATOM systems could even offer as many as 128 slices upon request.

In 2005, Siemens became the only CT manufacturer to turn its back on the race for ever-greater numbers of detector rows. Instead, it decided to focus on the completely new dual source technology. The move was viewed as a risky one, but it soon became apparent that the venture had been worthwhile: A few weeks after the first SOMATOM Definition was installed, experts estimated that cardiac CT could replace many of the approximately 600,000 catheter examinations performed each year. Clinical studies documented this technique's benefits, especially for cardiac imaging, the field in which computed tomography really excelled. Among other findings, researchers from Zurich University Hospital showed that SOMATOM Definition, could perform a cardiac scan with significantly less dose than conventional computed tomography. Siemens built on this success and on its experiences with dual source technology. In 2009, Siemens launched a new model that was once again the fastest CT scanner in the world at the time: SOMATOM Definition Flash.

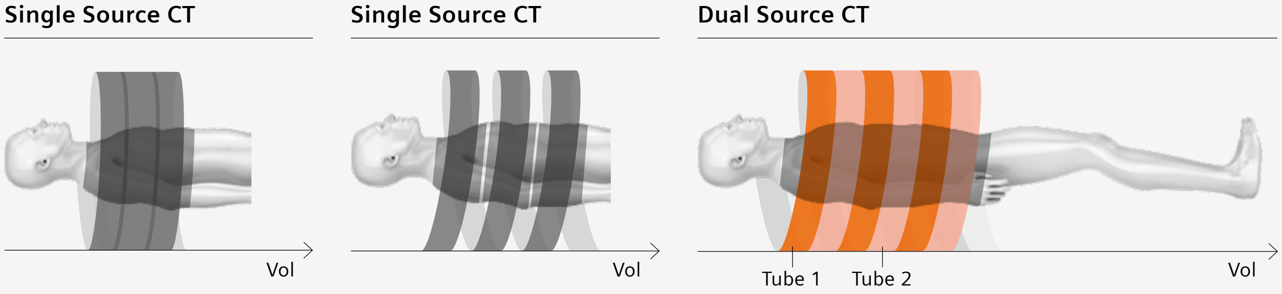

A foot scan with dual energy, Grosshadern University Hospital, Munich, 2007


Biograph mCT, 2008


syngo.CT Cardiac Function software, 2013

An example from cardiac imaging provides a vivid picture of the advances that had been made with SOMATOM Definition Flash. Previously, producing detailed images of the heart with as few artifacts as possible had required doses averaging between 8 and 30 millisieverts. SOMATOM Definition Flash needed less than one millisievert to do the job. A number of factors made this possible, including improved and specialized *syngo* programs and, above all, the premium scanner's outstanding speed. The gantry rotated around the patient in 0.28 seconds, almost four times per second. At the same time, the patient was moved through the scanner twice as fast as in conventional systems in use at the time. This meant that a person two meters tall could be scanned from head to toe in less than 5 seconds. A chest scan took 0.6 seconds and a cardiac scan just 0.25 seconds – less than half a heartbeat.

To further reduce the radiation dose, Siemens developed an innovative mathematical method of processing images. The IRIS "iterative reconstruction in image space" algorithm ran much faster than previous methods, despite the additional calculations involved, and made it possible to reduce the dose by a further 60 percent. The first systems were equipped with the new method in the spring of 2010. A year later, Fast Care software helped clinical personnel optimize dose and streamline workflows. Reducing the dose any more would lead to "noise" in the image, causing artifacts and diminished image quality – unless an even more efficient detector was developed, that is. The leap from xenon to solid-state detectors had already yielded significant improvements in converting X-ray signals. But this second generation of detectors had a weak point that affected image quality: After the X-rays were converted to light signals, the photodiode transmitted them to a converter that transformed the analog electrical impulses into digital ones. This took place via several hundred wires. The longer these wires were, the greater the electronic noise – and the greater the electronic noise, the worse the image quality. Siemens launched the first detector that eliminated almost all of these wires in 2012: In the Stellar detector, all of the electronics used for signal conversion are combined in a single chip located directly under the photodiode.



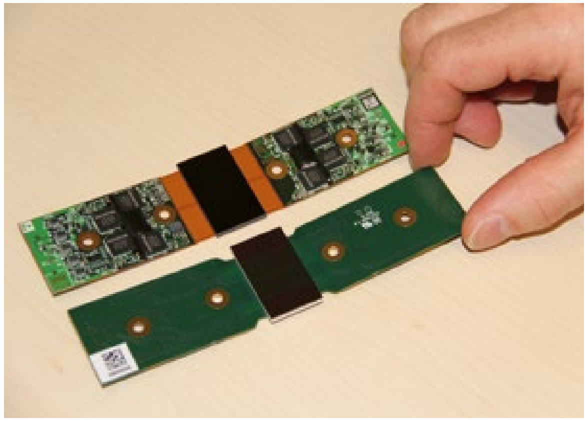
Dual Source CT SOMATOM
Definition Flash, 2009

During the early stages of the six-year process of developing the Stellar detector, it was not yet clear whether it would actually be possible to combine the photodiode and converter. To replace the wiring, about 90 contacts per square centimeter, each just 0.1 millimeter in diameter, had to be etched through a silicon plate. There were also several layers of oxide isolating the tiny contact holes from the silicon. In cooperation with semiconductor manufacturer ams AG, the engineers at Siemens made this completely new electronic design a reality. The extremely short transmission routes significantly boosted signal quality. Stellar reduced electronic noise by as much as 30 percent, which brought a comparable dose reduction – with improved image quality at the same time.

The outer structure of the Stellar detector was the same as in conventional Siemens detectors. The rest of the system architecture remained unchanged, and current scanners such as SOMATOM Definition Flash could easily be upgraded with Stellar. SOMATOM Definition Edge, the new high-end model with single source CT in 2012, came with the new detector technology as standard. With Stellar, the system visualized structures as small as 0.3 millimeters. This system also marked the introduction of a new dual energy technology in single source CT. It needed significantly less radiation than was customary for scans performed with this method using one X-ray tube.

Reducing the radiation dose also played an important role in the development of the Vectron™ X-ray tube in 2013. The operating voltage of X-ray tubes can be set to between 70 and 150 kilovolts (kV). To keep the radiation dose low, especially for CT scans performed using contrast media, many radiologists prefer 70 kV or 80 kV. With conventional tubes, however, only children and slender people could be examined using this method, known as "low-kV" scanning. At voltages this low, the X-ray tubes simply did not have enough power to scan larger patients. The Vectron tube eliminated this technical limitation. It had more than enough power reserves – over twice the amount of other CT tubes – to scan even people with larger bodies using the low-kV method. In addition, the contrast-to-noise ratio was so high that it was even possible to reduce the amount of contrast medium used in CT angiography.

Spiral CT, multislice, UFC, the Straton and Vectron tubes, sliding gantry, dual source, dual energy, the Stellar detector – these and many other hardware and software developments over the last 40 years have made Siemens the leading innovator in computed tomography. The current system families for the year 2015 are the product of years of experience and cooperation with scientists, researchers, and medical professionals all over the world. The portfolio today ranges from energy-efficient entry-level models to high-end scanners with two X-ray tubes, and from systems for routine clinical applications to highly specialized trauma room CT units on rails. Scanner families that have stood the test of time for many years, like Biograph and Symbia, are always at the forefront of advances in technology. They are joined by new product classes such as SOMATOM Perspective and SOMATOM Scope. Introduced in mid-2014, SOMATOM Scope is an all-around CT for routine clinical use. It has ultra-low operating costs and needs just eight square meters of space.



A conventional detector element (top) and Stellar (bottom), 2012

The SOMATOM Scope, which needs just eight square meters of space, 2014

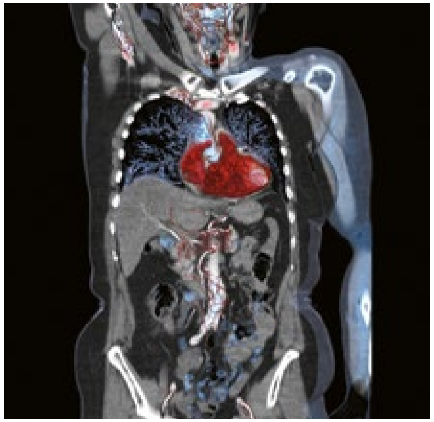
A dual energy scan with the SOMATOM Definition Edge, University of Erlangen-Nuremberg, 2014

SOMATOM on rails, Frankfurt University Hospital, 2014

SOMATOM Perspective with up to 128 slices, 2014


SIEMENS
SOMATOM Force

SOMATOM Force, 2013



Upper body scan, Mannheim University Medical Centre, 2013

SOMATOM Force in Mannheim, 2013

40 years of experience in a single unit

The prototype of what was once again the fastest CT scanner in the world was set up at the University Medical Centre Mannheim in late 2013. The gantry held a child carrier with a small, wriggly patient – a one-year-old boy who had been admitted to the hospital with a suspected case of pneumonia. An X-ray image had been taken, but the results were inconclusive. Then things moved very quickly. SOMATOM Force scanned the infant's chest in just 0.3 seconds – without any artifacts from his movements or breathing getting in the way of the final image. The image showed tiny areas of inflammation in the lung tissue, and it did so at a dose radiation no higher than that of a conventional X-ray. This finding allowed the doctors to initiate suitable treatment for the young patient right away.

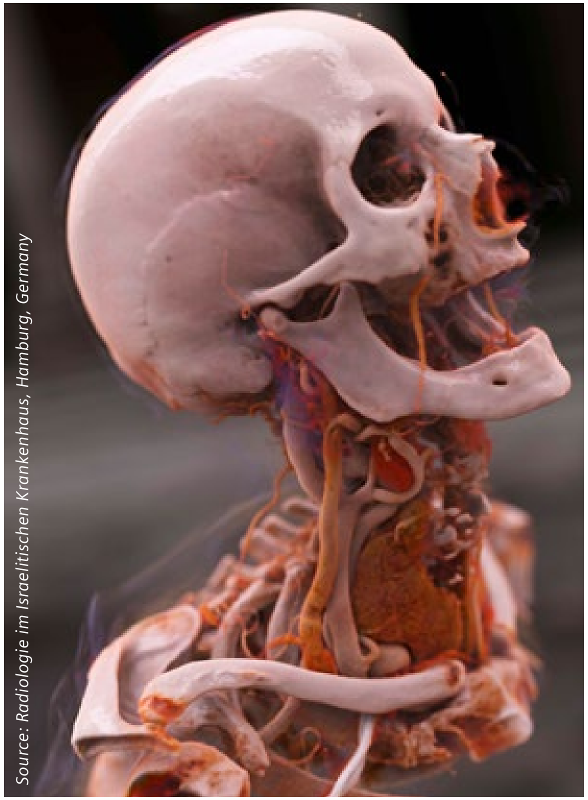
SOMATOM Force is the world's most powerful CT scanner, pushing the limits of present-day technological feasibility. The system took a 600-person team five years to develop. It brings together all of the high-end components from Siemens and pushes them even further. The 1.6-tonne gantry rotates around the patient four times a second. That's like a Mercedes E-Class car tracing a circular path on a small, round coffee table with five times the acceleration force of a fighter jet. At the same time, the two Stellar detectors and the Vectron X-ray tubes have to be kept in position with the utmost accuracy, down to not only the millimeter, but even the micrometer. Combined with the table speed (which has been increased from 45 to 73.7 centimeters per second), the fastest on the market – this means the system can now scan an adult's entire upper body in under one second. The achievable resolution is 0.24 millimeters, as compared with the 0.33 millimeters possible with the previous model. Without any compromises in image quality, SOMATOM Force scans a lung at a dose of just 0.1 millisieverts – about the same as the natural level of radiation exposure occurring on a flight from Germany to Argentina.

Looking to the future

Over the years, computed tomography has far surpassed the high expectations placed on it in the early pioneering days. The extent to which the technology has developed just since the turn of the millennium can be illustrated with a simple comparison: In the late 1990s, a CT scan of a thorax usually provided 40 to 50 slice images for diagnosis. Fifteen years later, when the full power and maximum image resolution of SOMATOM Force were used in an examination, the scan would produce at least 2,000 to 3,000 slice images. In order to put this enormous quantity of three-dimensional data to constructive use, the engineers from Siemens spent a number of years working on a host of new tools. The aim was to convert big data into smart data.

Cinematic images of the body

Cinematic Rendering images impressively demonstrate the results that sophisticated software can obtain from the right hardware. As the name of the technology suggests, Klaus Engel and Robert Schneider – two of the leading visualization experts at Siemens Healthineers – based the underlying concept for their invention on the computer-generated effects seen in the movie industry. The algorithm in the software uses three-dimensional patient data to generate photorealistic images of anatomy by simulating the physical properties of light in datasets obtained from the patient’s body. However, whereas effect rendering in the movie industry only considers light reflected by the surfaces of animated characters’ bodies, the algorithm for Cinematic Rendering technology takes account of much more complex factors, such as photon scattering in the tissue. The light propagates through the three-dimensional datasets naturally and casts realistic shadows, and it is this realistic shadowing that makes the images so lifelike – because our eyes are trained to identify the structure of objects based on minute differences in shading.



The thyroid gland and bones of the head and neck region, visualized using Cinematic Rendering in 2015

Since 2017, the *syngo*.via software has allowed Cinematic Rendering images to be generated using CT or MRI scans with a few clicks of the mouse. It also has a filter function that allows the operator to hide different types of tissue – for example, in order to leave only the bones visible in an image used to examine the skeleton. Cinematic Rendering has enormous potential, and several studies are currently investigating the added value that the technology offers in various medical disciplines, including forensics. The photorealistic images can, for instance, facilitate communication between physician and patient, or help surgeons to plan operations better. Cinematic Rendering has already found successful applications in teaching: Franz Fellner, head of the Central Radiology Institute at Kepler University Hospital Linz, worked with Engel and Schneider to further refine the technology and, since 2015, has used the innovative images to teach anatomy to medical students on a huge projection screen. In 2017, Engel, Schneider, and Fellner were one of three teams of scientists to be nominated for the German Future Prize, one of Germany’s most prestigious awards for technology and innovation.

The white cables on this Cinematic Rendering image belong to an ECG unit that was connected to the patient during the CT scan

Source: Qilu Hospital, Shandong University, Jinan, P. R. China

Fewer resources, better results

The number of CT scans increased significantly over the course of the 2010s. Around the world, more and more clinical guidelines now recommend the use of computed tomography in critical decision-making. At the same time, changing healthcare systems and demographics mean that healthcare providers must attend to an ever-increasing number of older and older patients while grappling with rising cost and time pressures. In short, to be successful in the transformation of healthcare, it is imperative to deliver more and better care – with fewer resources.

For the development of the completely new SOMATOM go. platform from 2016, Siemens Healthineers worked closely with users and patients from numerous countries around the world to further optimize the systems for everyday clinical use and make day-to-day working life easier. In a series of interviews and workshops during the design phase, over 500 radiologists, radiology assistants, CFOs, patients, and referring physicians were asked what they felt were the key features of an optimum CT scanner. Their answers showed that a CT scanner should be simple and efficient to operate while delivering high-quality images and meeting clinical and financial requirements – and it should make no difference whether the user is operating the scanner in a rural area of an emerging economy or in the state-of-the art, networked radiology centers of North America or Europe.

The SOMATOM go. platform provides extraordinarily straightforward and flexible operation. A lightweight,

SOMATOM go.Up –
easy operation via a tablet

high-resolution tablet allows the user to perform a variety of tasks – from checking the patient's details on the way to the waiting room to preparing for the scan at the gantry itself. Thanks to Scan&GO technology, the whole scan involves just a few operations. Moreover, automated postprocessing of the examination makes the scanner even easier to use.

Simplified workflows mean that the scanner can even be operated by staff who have not been specially trained on the system – for example, in the event of emergency examinations during night shifts. Standardization of processes helps to avoid errors and therefore provides radiologists with additional certainty when it comes to the diagnostic reliability and quality of the images. This eliminates the need to repeat scans and does away with unnecessary waiting times – regardless of whether it's an orthopedic or an oncological examination.

The new operating concept at the heart of the SOMATOM go. platform provides numerous other advantages, including in relation to patient comfort. As the radiographer controls the scanner from the tablet, they no longer need to move back and forth between the examination room and control room. Instead, they can remain close to the patient while preparing for the scan. Many patients appreciate this proximity and feel that it inspires more confidence – which is particularly important when it comes to children.

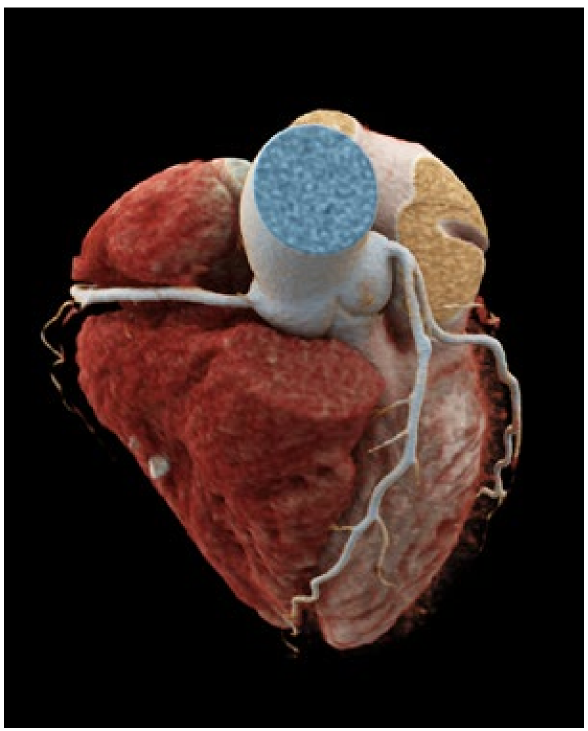
A new kind of intelligence

One of the most important topics in medicine today is the expansion of what is known as precision medicine. This term encompasses many different aspects, including the patient experience – which played a significant role in the development of the SOMATOM go. platform. In general terms, precision medicine refers to current developments aimed at finding the right treatment at the right time for every patient. This involves considering the individual patient's condition as precisely as possible during prevention, diagnosis, and treatment. One of the key pillars of precision medicine is "intelligent imaging."

SOMATOM go.Now and SOMATOM go.Up, 2016

Fascinating insights from orthopedic images obtained with SOMATOM go.Now, Tadokoro Clinic, Saitama, Japan

Intelligent imaging leverages the possibilities of digitalization to help users unlock the full potential of various systems. myExam Companion, which Siemens Healthineers presented along with SOMATOM X.cite at RSNA 2019, marks the beginning of a new generation of intelligent imaging. As a smart assistant, myExam Companion helps users find the correct configuration for CT scans in order to obtain the best possible clinical image and the correct dose for each individual patient. For instance, the patient's positioning during the scan has a significant impact on the required dose. SOMATOM X.cite uses various technologies to detect a number of patient characteristics automatically. One example is its FAST 3D Camera, which measures the size and contours of the body so that the patient can be placed in the optimum position on the table. As scan preparation continues, myExam Companion assists the user by asking simple questions – "Can the patient hold their breath? Does the patient have a stent?" – in order to adapt the scanning configuration to the patient as closely as possible. SOMATOM X.cite then performs all of the complex technical adjustments itself.



SOMATOM X.cite is a single source CT scanner that is brimming with high-end technologies from Siemens Healthineers, such as the Vectron X-ray tube that was previously only used in SOMATOM Force. The refinements of 2019 include a number of new features that can make the examination less burdensome for patients. For example, a new video camera in the gantry means that the patient and operator are in constant contact. Intuitive audiovisual signals tell patients when to breathe, when to prepare not to breathe, and when to hold their breath and for how long. During trials, numerous patients reported that this audiovisual breathing support made it much easier for them to relax before and during the scan.

Image of a heart produced with SOMATOM X.cite in 2019

Learning for the future

myExam Companion is a sort of smart assistant that helps users prepare for an optimum scan. Other digital assistants based on artificial intelligence (AI) reduce the burden on radiologists after the scan, when it comes to assessing diagnostic images and making decisions. AI-Rad Companion Chest CT can recognize potentially pathological changes in organs and tissue. The software discerns and highlights structures in CT scans of the thorax and marks abnormalities. Working with enormous, complex volumes of data, the AI can spot patterns quickly and accurately because the algorithm has "learned" what to look out for based on high-quality training data. In the process, AI systems such as AI-Rad Companion Chest CT are quite literally learning for the future. The more "training data" is made available to the system, the more accurate its analyses become.

Even in the future, however, AI-Rad Companion Chest CT will not replace radiologists; rather, it will simply relieve them of routine activities so that they have more time to deal with complicated diagnoses. Using other intelligent algorithms, Siemens Healthineers succeeded in simulating the heart of a real patient in 2019. In a joint research project with University Hospital Heidelberg, cardiologists used imaging data, laboratory diagnostics, and ECG measurements to create a digital twin of a real patient's heart in order to tailor the treatment of heart diseases specifically to the individual patient. The digital twin can be used to conduct preliminary tests of certain medications or surgeries in a digital environment in order to gauge the chances of success. With digital twins of other organs already in development, algorithms are set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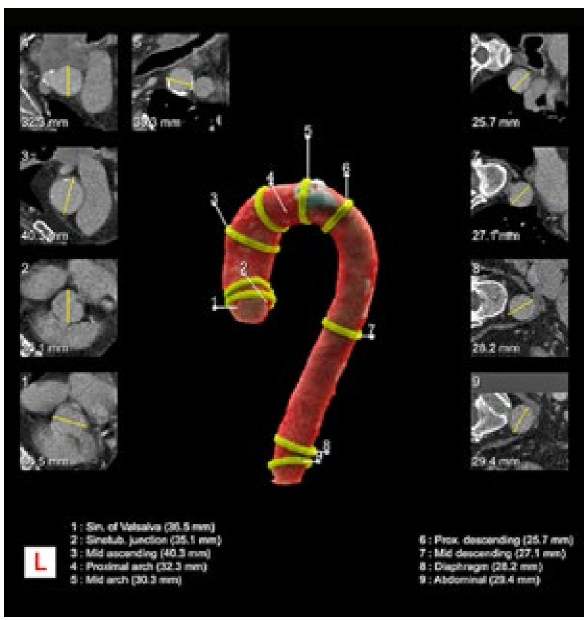
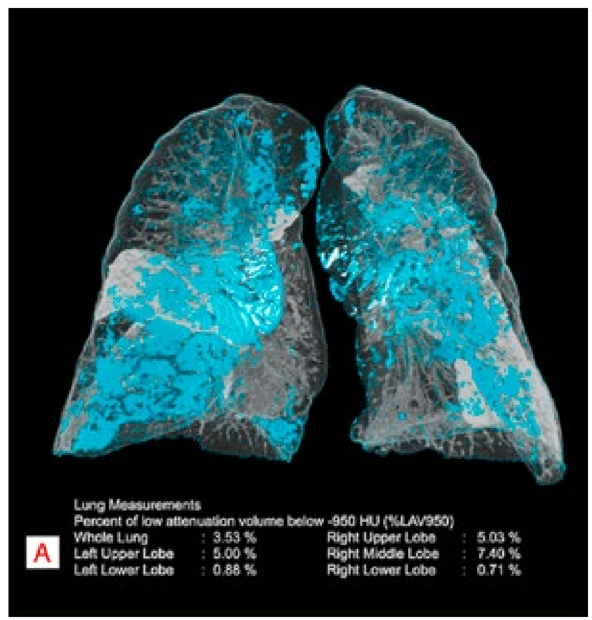
SOMATOM X.cite
with myExam Companion

to take on an increasingly important role in imaging. AI systems offer a promising way of supplementing human abilities in order to improve decision-making. The aim is to support sounder and more accurate decision-making while also reducing the workload and the potential for human error.

Digitalization could be as transformational for medicine as the discovery of X-rays was in its day. Today, in Siemens Healthineers Digital Ecosystem, applications such as teamplay myCare Companion support the networking of patients and healthcare teams, allowing care to be provided remotely to patients with chronic diseases, such as cardiac insufficiency. Using *syngo* Virtual Cockpit, specialists from one hospital can connect with scanners from Siemens Healthineers at hospitals elsewhere in order to provide their colleagues with expert assistance. For example, this allows healthcare providers to conduct specialized examinations that rely on specific user expertise across all of its locations without requiring patients to travel long distances.



Among other things, the intelligent software assistant AI-Rad Companion Chest CT measures deviations and compares them with reference values



AI-Rad Companion Chest CT automatically marks abnormalities

SOMATOM comes to the patient

For many patients, the journey from hospital bed to radiology department can be a strenuous exercise or even carry serious risks. If a stroke patient in the ICU connected to stationary equipment – such as a respirator – has to be transported to a CT scanner, they must be switched over to portable equipment, lifted out of bed at the scanner, and then transferred again and reconnected to the stationary equipment once the examination is complete. To improve patient safety, Siemens Healthineers has developed a mobile CT scanner that allows head scans to be performed directly at the patient's bedside. Launched in 2019, SOMATOM On.site is extremely easy to use: The headboard of the bed is removed, and the patient stays where they are – with all of the necessary equipment connected. During the scan, only the inner – or rear – element moves, while the front gantry section stays still, and the patient is not affected by the movement of SOMATOM On.site whatsoever. The entire process – from preparing for the scan to transferring the data to the radiology department – requires very few members of staff and only takes a few minutes.

SOMATOM On.site features a gantry based on a completely new concept. The telescopic construction of the lead-shielded gantry means that, during the scan, the specially developed X-ray tube and the detector move away from the front patient bore, reducing radiation scatter. Additional lead shields can be attached to the bore opening in order to protect nearby patients and staff. Moreover, myExam Companion guides users without specific training and of all levels of experience through examinations and helps them to achieve consistent results. Indeed, the image quality of SOMATOM On.site almost matches that of permanently installed scanners.

With SOMATOM On.site, Siemens Healthineers brings head CT scanners directly to the patient's bedside, 2019

In fall 2020, Siemens Healthineers celebrated the shipment of the 55,555th CT scanner in Forchheim

Same principle – a new world of possibilities

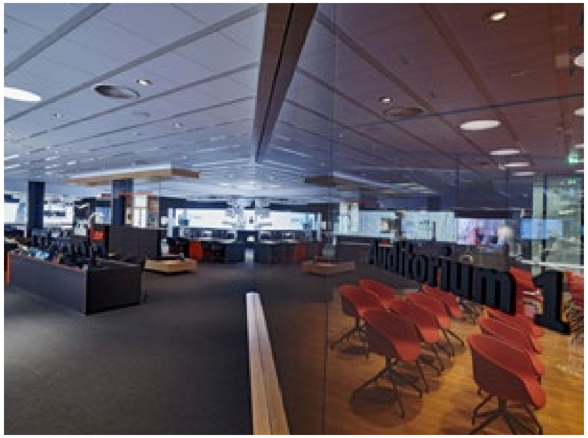
In autumn 2020, some 50 years after Godfrey Hounsfield's "crazy idea," Siemens Healthineers delivered its 55,555th CT scanner. In hospitals and health centers around the world, computed tomography is used, among other things, to plan operations, to monitor treatment progress, and in emergency situations such as for accident victims or in cases of suspected stroke. The latest systems have transformed clinical practice. Today, the required dose is so low that CT scanners are even used for regular examinations to monitor treatment progress or for the early detection of diseases – including to examine the lungs of smokers. At the same time, modern CT scanners still operate according to the basic principle thought up by Godfrey Hounsfield – but they are worlds apart from early devices in terms of technology. Major milestones to emerge from Siemens Healthineers, such as Spiral CT and Dual Source CT, will certainly not be the last revolutionary inventions in the history of computed tomography – for as Godfrey Hounsfield once remarked: "Many discoveries are probably lurking around the corner, just waiting for someone to bring them to life."

From small factory to global player

Detector production at the main plant in Erlangen, 1981

In 1975, Siemens built the first SIRETOM in a relatively small factory building in Erlangen and delivered it to Frankfurt. Today, Siemens Healthineers produces thousands of systems a year at four sites spread around the globe, and ships them all over the world. The company's factory in Forchheim is home to one of the largest and most advanced computed tomography production facilities worldwide. Siemens Healthineers produces CT scanners also in Shanghai and Bengaluru – and, since August 2012, worldwide sales of the SOMATOM family have been supported by a 6,000-square-meter factory in Joinville, Brazil. The sites are seamlessly connected with one another. In close cooperation with other business units, teams work on hardware innovations and develop new software applications. All of the X-ray tubes in CT scanners from Siemens Healthineers are produced by the company's own X-ray plants, which are located in Rudolstadt, Forchheim, and the Chinese city of Wuxi.

In 2017, Siemens Healthineers opened a new office and development building in Forchheim with space for up to 2,000 employees



Siemens Healthineers Experience Center in Forchheim allows visitors to experience numerous new technologies and applications in an area measuring over 1,200 square meters

Forchheim, Germany

In 1986, Siemens opened a small branch location in Forchheim, Upper Franconia, some 20 kilometers from the headquarters in Erlangen. While the site initially had about 280 employees producing sheet metal housings for medical equipment, it has now become one of the most important locations for medical technology at Siemens Healthineers, with a staff of around 3,100. The company began expanding the site at regular intervals right from the outset, and eventually moved its steadily growing CT manufacturing activities from Erlangen to Forchheim.

In November 1994, after 13 months of construction work, the company began operating one of the world's most advanced factories for medical technology: the only CT production site in Europe and an expanded plant for angiography systems. The two units were closely interconnected in terms of development, manufacturing, quality management, international logistics, and marketing. The site has received numerous awards and distinctions over the years, including the title of "Factory of the Year 1998."

As the plant continued to grow, a 25,000-square-meter office and development building opened its doors in spring 2016. As of 2020, Siemens Healthineers is investing some €350 million over several years in order to expand the existing facilities at the Healthineers Campus in Forchheim. These plans will see the construction of a state-of-the-art factory for medical technology components, as well as a new development and logistics hub.

Shanghai, China

The history of Siemens in China dates back to the era of the Qing dynasty. In 1872, the company supplied China's first dial telegraph. Seven years later, Siemens installed a lighting system, including a power plant, at the Shanghai harbor. The bustling city in eastern China also became the headquarters of Siemens Shanghai Medical Equipment Ltd. (SSME), which was founded in 1992 as the first Chinese production site for Siemens medical technology.

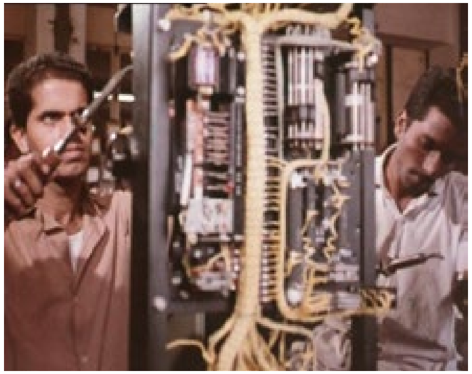
In the space of two decades, the plant has grown from a simple assembly factory to become a major site with activities spanning development, production, customer service, and training for engineers and specialized workers in the Asia-Pacific region. Alongside CT scanners, SSME also produces ultrasound systems, X-ray units, and medical components. The plant, which is located in the heart of the Shanghai International Medical Zone, grew by more than 32,000 square meters in 2013 and now occupies a total area of over 100,000 square meters.

Production of CT scanners at the Shanghai factory of Siemens Healthineers in 2007

Left: The electromedical department of Siemens China Co. in Shanghai in the 1930s.

Right: The plant's extension is opened in 2013.

The SOMATOM go. family is developed and produced in India



Production at the Worli factory, 1967

Bengaluru, India

The history of Siemens in India also stretches back to the second half of the 19th century. In 1867, planning and construction work began on the Indo-European Telegraph Line, which connected Kolkata and London until 1931. Siemens medical technology products have been used in India since the early 20th century, and the first Indian production of X-ray units began in the locality of Worli in 1959. Today, the factory in Bengaluru – formerly known as Bangalore, and the third-largest city in India after Mumbai and Delhi – is one of the largest sites of Siemens Healthineers. Staff at the plant develop and manufacture products, including SOMATOM go. CT scanners, for Southeast Asia, Africa, Eastern Europe, and South America.

In 2020, Siemens Healthineers announced that it was expanding its existing operations in India. Around 50% of the company's software engineers already work at the research and development center in Bengaluru, and there are plans to hire an additional 1,800 digitalization experts over the next ten years. As one of four innovation hubs run by Siemens Healthineers around the world, the Bengaluru campus will bring together various centers of competence under one roof, including those for digital technologies such as artificial intelligence, for immersive technologies such as augmented and virtual reality, and for user experience and cybersecurity.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CEOs of computed tomography business

1972–1984	Friedrich Gudden (CT development)
1985–1986	Walter Schwarze
1986–1990	Wolfgang Feindor
1991–1995	Peter Bertsch
1996–2000	Klaus Hambüchen
2000–2004	Richard Hausmann
2004–2008	Bernd Montag
2008–2011	Sami Atiya
2011–2015	Walter Märzendorfer
2015–2019	André Hartung
since 2019	Philipp Fischer

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