



Siemens Healthineers Historical Institute

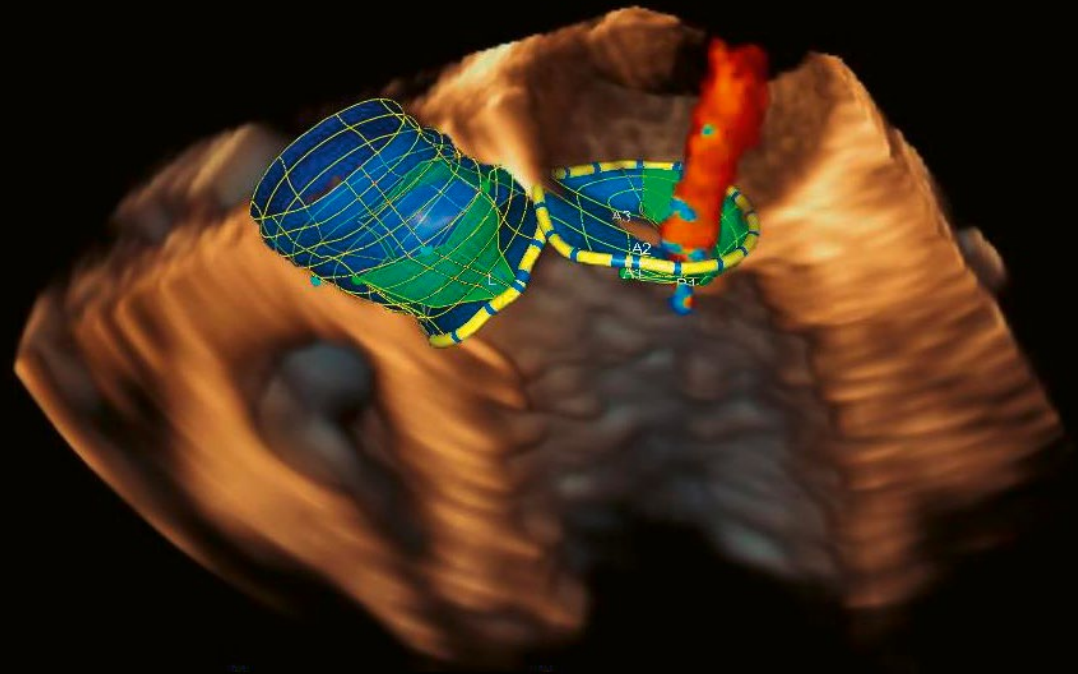
The history of ultrasound imaging at Siemens Healthineers

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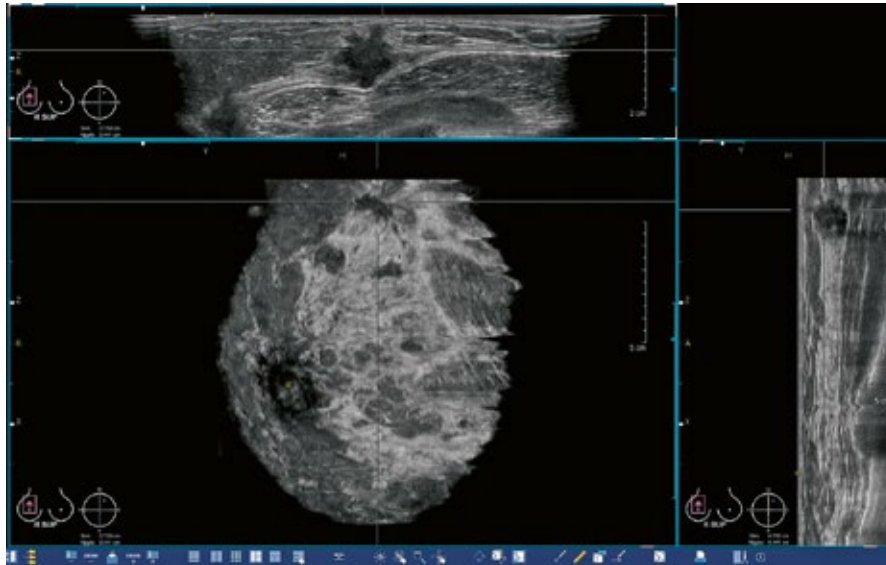
Ultrasound imaging in medicine and at Siemens Healthineers

Sometimes, significant developments begin with a bang: When Wilhelm Conrad Röntgen discovered X-rays in 1895, it quickly became clear that images from inside the body would revolutionize medicine. Most of the time, however, major developments begin with a steady, tentative search for new possibilities through a process of experimentation and theoretical research. At the time of the first experiments into the medical applications of ultrasound, no one could have imagined that the technology would, over the years, become the most widely used tool in diagnostic imaging. First, the ultrasound pioneers had to face some fundamental questions of direction: Was the research only interesting from a theoretical perspective, or could the findings be applied to everyday clinical practice? Was ultrasound better- suited to therapy or diagnostics? What structure did an ultrasound system need in order to be powerful, yet convenient for patients and physicians alike? This brochure provides answers to these questions and many more, focusing on the stories behind the milestones at which Siemens Healthineers either drove forward or helped to shape the development of ultrasound technology. We will begin, however, by considering the benefits of ultrasound diagnostics to modern medicine, and by looking at the current state of the art and the technology's significance to Siemens Healthineers as one of the world's leading healthcare companies.

When most people hear the word ultrasound, they think of scans during pregnancy—pictures of a baby within a woman. Indeed, it was in the field of gynecology that ultrasound diagnostics experienced its first boom in the mid-1960s, when the Siemens Vidoson™ ultrasound scanner made it possible to see fetuses moving inside the womb for the first time. At that time, the images may well have appeared to the untrained eye as nothing more than patterns of clouds and lines, but even these basic images allowed a trained operator to measure the size of a baby's skull or even to observe the heartbeat. Today, thanks to sophisticated technology and highly specialized software, ultrasound images bear little resemblance to the rudimentary scans of 50 years ago. Today, expecting parents can see whether their baby is a boy or girl, even details such as the eye lenses and the tooth buds can be visualized. Two- or three-dimensional images show the baby moving inside the womb, sucking its thumb, and pursing its lips. These images can be saved for the parents to take home, even on a smartphone, making them available even to the layperson. Of course, the true significance of ultrasound lies in its medical benefits. Now that gynecologists can see the baby inside the womb, they can easily treat many diseases that an unborn child would not have survived in the past. If anemia is diagnosed, for example, the fetus can be given blood transfusions to return to full health.



3D visualization of a fetus during the last trimester of pregnancy



Three views of the breast:
axial, lateral, and coronal

By providing medical professionals not only with a safe and gentle way of examining both mother and child, but also with real-time moving images on a screen, ultrasound diagnostics first achieved widespread acceptance in obstetrics. Other medical specialties were soon to follow. As ultrasound imaging can produce contrast-rich, high-resolution moving images of all organs that contain water or are rich in blood, it is now used in virtually every discipline: for example, to examine the heart and blood vessels, the liver, the kidneys, or the muscular system. The rate of blood flow through vessels can be measured to investigate vasoconstriction or organ function. Today's systems are remarkably powerful. One example of the latest technologies, which will become increasingly important in the future, is image fusion: Sophisticated software can overlay ultrasound images with three-dimensional patient

scans obtained using computed tomography (CT) or magnetic resonance imaging (MRI). This image fusion process combines the strengths of various imaging techniques and provides physicians with additional clinical information that can help in the assessment of complex cases and planning of operations.

Modern medical ultrasound systems are the culmination of about 80 years' experience. Siemens Healthineers made significant contributions to the development of ultrasound diagnostics, often with pioneering breakthroughs that left a lasting mark on the technology: from seminal research into ultrasound therapy and cardiac diagnostics to the invention of real-time imaging, not to mention modern innovations such as the world's first wireless ultrasound system.



Echoes from inside the body

How sound waves become images

What is ultrasound, and how does it propagate?

This question is easy to answer if you first put it in more general terms: How is the sound we hear produced, and how does it reach our ears? This is relevant because audible sound has exactly the same physical properties as ultrasound; the only difference is that ultrasound waves oscillate so many times per second that they are inaudible to the human ear.

All sound waves, whether audible or inaudible, move through space mechanically and are therefore reliant on the presence of matter: The air that surrounds us is made up of tiny particles, and principally of molecules of nitrogen and oxygen. If the air particles collide with something, such as a loudspeaker or a moving car, the impact is transmitted from one particle to the next in a chain reaction. The air becomes denser due to the impact, and its pressure increases, leaving behind a layer of air that is less dense—that is, where the pressure is lower. The resulting oscillations, or waves, are the mechanism by which sound propagates through space. If sound waves collide with an ear, they cause the eardrum to vibrate at the same rate as the original collisions with the air particles. The eardrum relays the vibrations through several stages before nerve cells ultimately convert them into electrical impulses and transmit them to the brain.

What people hear depends primarily on two properties of sound: the frequency at which the waves oscillate and the pressure with which they reach the eardrum. The frequency refers to the number of oscillations per second and is stated in units of hertz (Hz). The average human ear perceives sound waves that are oscillating between approximately 16 and 20,000 times per second. Sounds at 16 Hz are very low in pitch, and sounds at 20,000 Hz are very high. The pressure of the sound affects first the volume—the higher the pressure, the louder the sound—and second how the waves behave in different materials, as sound waves propagate not only in air but also wherever there are particles—in other words, in solids and liquids too. In this context, the speed depends strongly on the material, and especially on its elasticity, density, and temperature. At a temperature of 20 degrees Celsius, the speed of sound is 343 meters per second in air, but it is more than four times as high in water, at 1484 meters per second. When sound is traveling through one material and comes into contact with another, such as when passing from air into water, the waves are reflected strongly at the boundary. Within the human body, for example, inside organs, the waves are reflected less strongly and in different ways depending on the tissue, and ultrasound diagnostics makes use of these differences in the echo.

The term ultrasound refers to sound waves oscillating between 20,000 and 1,000,000,000 times per second or, in technical terms, at frequencies of between 20 kilohertz (kHz) and 1 gigahertz (GHz). Medical ultrasound, or ultrasound imaging, typically uses frequencies of between 2 and 30 megahertz (MHz), that is, of 2 million to 30 million oscillations per second. In the human body, ultrasound waves propagate in the same way as in liquids. The speed of the waves varies depending on the tissue; they are sometimes reflected more strongly, and sometimes more weakly. Natural principles provide the basis for the technology used to generate artificial ultrasound waves for imaging and for the process of ‘listening’ to the echo.

Borrowed from nature: the foundations of ultrasound diagnostics

Anyone who has heard their own voice as an echo is familiar with the principle of ultrasound imaging. The vocal cords produce sound waves, which travel through the air and are reflected by surfaces such as bridges or cliffs before returning after a short time. As a result, you hear the sound you made reflected back to you; although it is quieter, it has the same pitch and therefore the same frequency. If you measured the exact time from the shout until the echo, taking the speed of sound into account, you could calculate the distance from yourself to the



reflective object down to the millimeter. With a more sensitive sensor than the human ear, it is even possible to determine size and shape, and to perceive movements. In the same way as bats 'see' their prey, ultrasound can help physicians to distinguish between diseased and healthy tissue in a patient's body.

Of course, this is a fairly general description; the details of the wave mechanics are far more complex. For now, the key element to understand is that frequencies in the ultrasound spectrum can provide considerably more information than audible sound because the waves are shorter and can therefore depict structures in finer detail. An ultrasound transducer emits short packets of waves—1000 waves per second, for example—that are then reflected inside the body. The reflection is not straightforward, however, as most tissues and organs have rough surfaces. Some of the ultrasound is scattered and refracted, especially at the boundaries, and some is absorbed within denser layers and converted into heat. When it comes to translating these complex echoes into images, ultrasound systems are constantly pushing the limits of technical capabilities.

How can ultrasound be generated artificially, and how are the echoes made visible?

Certain crystals and ceramics exhibit a physical phenomenon—the piezoelectric effect—that can be used both to generate and pick up ultrasound waves. Piezo comes from ancient Greek and means press or squeeze. If an electrical voltage is applied to a piezoelectric crystal, the crystal deforms; if an alternating voltage is applied, the crystal starts to vibrate and to emit sound waves. This effect also works in reverse: If a sound wave exerts pressure on the crystal, the crystal deforms. An electrical charge is generated inside the crystal, and this can be measured. The greater the pressure on the crystal, the higher the voltage. From the voltage, it is possible to gain all of the information that the ultrasound has acquired from the tissue.

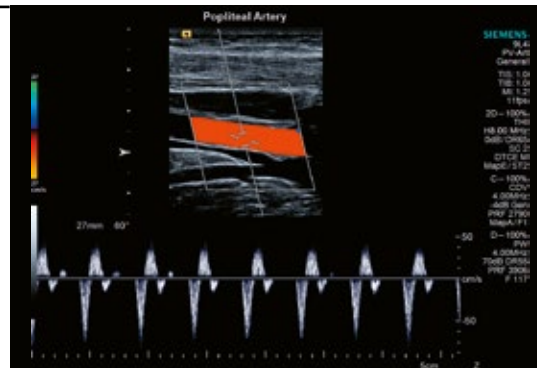
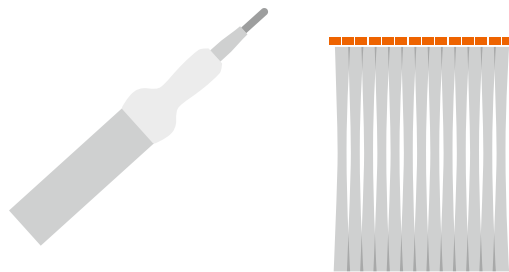
The piezoelectric elements are located in the ultrasound system's transducer, which acts as a transmitter and a receiver at the same time. Nowadays, the task of converting the voltage measured in the crystal into an ultrasound image

is performed by the system's digital signal processing technology using mathematical algorithms. In this context, the processing power of an ultrasound system is hugely important: The echo contains an enormous amount of information about the structure and position of the body tissue, which is generally depicted at a rate of up to 30 frames a second. Software also plays a significant role. Modern ultrasound systems offer numerous functions that optimize the resulting image for the specific type of examination.

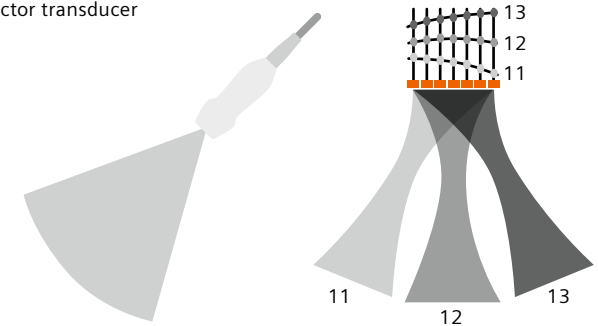
Targeted insights into the body

If you look at several different ultrasound images, you will notice that these body scans do not always have the same outline. The body segment either fills the entire image or is shaped like a fan or coffee filter. These different outlines are produced by the different types of transducers. (A variety of synonyms are used for the term transducer, including ultrasonic probe and applicator.) The shape of the transducer can be used to determine the arrangement of piezoelectric crystals inside. An arrangement in rows is technically referred to as an array. Depending on

Linear transducer



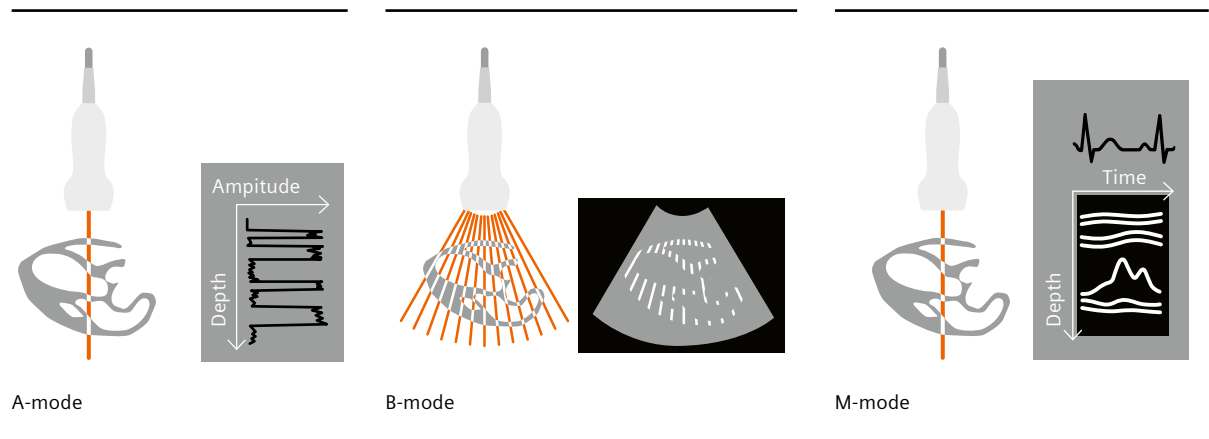
Sector transducer



the application, different arrays produce the best picture: In the linear array transducer, approximately 400 piezoelectric crystals are arranged behind one another in a straight line. The sound waves propagate in the same direction and with even spacing, resulting in a rectangular image. As picture quality and resolution are very high close to the transducer, the linear array is particularly well-suited to the examination of tissues close to the surface, such as the thyroid gland.

In older sector array transducers, the piezoelectric crystals rotate around an axis mechanically; in modern systems, individual groups of crystals are triggered electronically. The sound emerges in a narrow beam that grows wider as the distance increases. The principal advantage of this fan-shaped beam is that it allows sonographers to examine even hard-to-access organs such as the heart by directing the beam through the ribs. The disadvantage is the lower resolution close to the transducer.

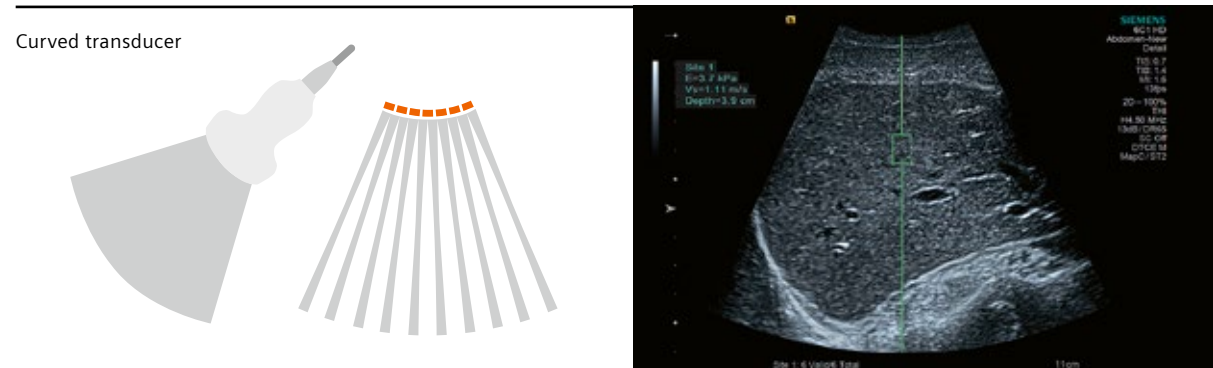
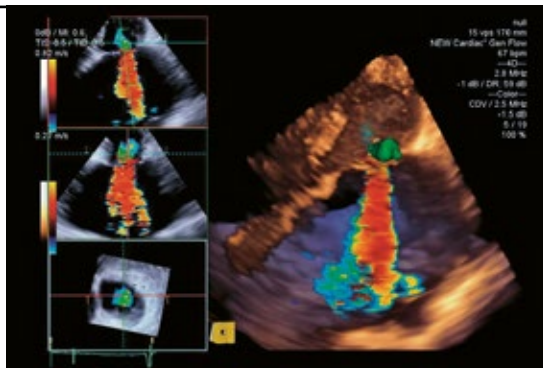
The curved array transducer is technically a mixture of the linear and sector array transducers and has the corresponding advantages and disadvantages.



The piezoelectric crystals are arranged in a convex pattern resembling the curvature of a lens. The contact area is smaller than that of a linear array transducer, and although the image resolution is not quite as high, it is considerably higher close to the transducer than with the sector array transducer. The curved array transducer is used primarily for studies of the abdominal region.

From the basic signal to a moving 3D image

The echo produced inside the body can be represented in a variety of ways, from a basic signal on a scale to a three-dimensional moving image. The ultrasound sampling method is referred to as the scan or mode, and there are four standard methods:



The oldest and simplest type of image formation is the one-dimensional **A-mode** (A: amplitude modulation). This method works in a similar way to the sonar technology used in shipping. The transducer emits an impulse, which is reflected by the wall of the heart, for example. The monitor displays the time taken for the sound to travel there and back in the form of a graph, with the x-axis showing the penetration depth and the y-axis showing the strength of the echo. This allows depths and distances to be measured but cannot be used to create an image of tissue structures.

The **B-mode** (B: brightness) represents the strength of the echo signal as dots of varying brightness on a

monitor. The stronger the echo, the brighter the dot. If the ultrasound beam is moved sideways, multiple adjacent lines are used to form a two-dimensional scan known as the B-scan.

The **M-mode** (M: motion) depicts the movement of organs in one dimension and can be used to measure speed and distances. This method is mainly used in cardiac diagnostics. The beam is aimed at the heart, and the movements of all its internal contours appear on the screen.

The latest ultrasound systems can generate multi-dimensional images from two-dimensional scans. 3D imaging allows the spatial representation of

structures within the bodies or organs of fetuses, for example. Supplementing these images with a further dimension—time—creates what is known as 4D imaging, whereby three-dimensional images are depicted in real time with only a minimal delay.

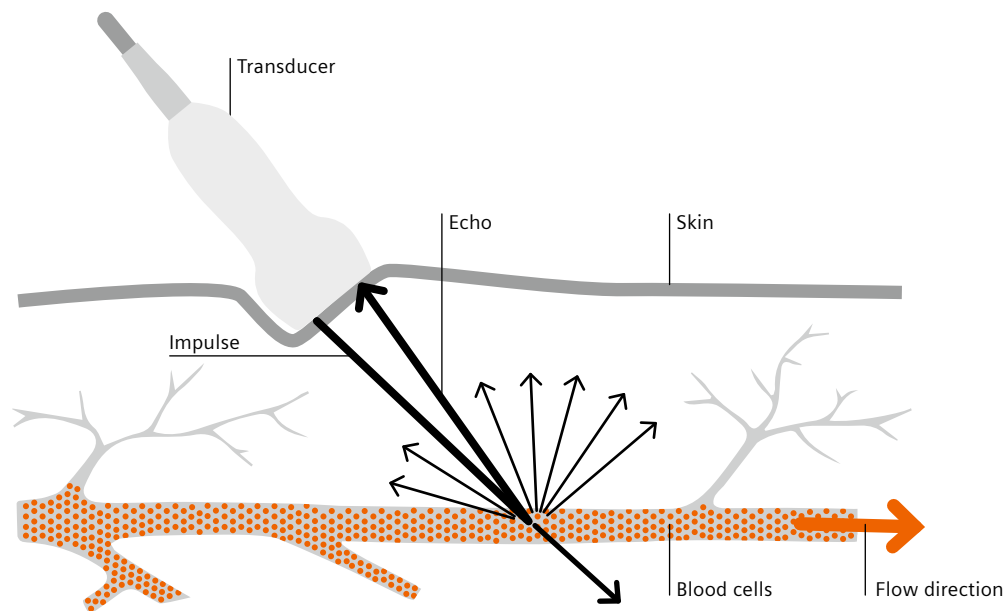
Watching the blood flow: What is the Doppler effect?

There is another property of sound waves that makes ultrasound diagnostics significantly more powerful: If the source of the sound—or the point of reflection—is moving, the wavelength (frequency) shifts. The faster the source is moving, the larger the shift. Known as the Doppler effect, this phenomenon can often be observed in everyday life and is particularly clear when sirens are used on moving vehicles. Next to a stationary ambulance, the signal tone has a constant pitch. However, if the vehicle is moving toward the observer, the sound waves are bunched together, making the tone sound higher; if the vehicle is moving away, the waves become more spread out, and the tone of the sound is lower. This shift in wavelength is therefore the cause of the differences in pitch.

If sound waves are pointed at moving liquids containing small particles (red blood cells, for example), the Doppler effect can be used to measure the flow rate. In medicine, Doppler ultrasound examinations are used to visualize blood flow through vessels and organs. For example, the displayed image allows sonographer to find constrictions, assess heart function, and even to spot whether blood is flowing in the wrong direction, for example, if the heart valves are not closing properly. Today, Doppler ultrasound is used in almost all medical disciplines.

Incidentally, the Doppler effect occurs not only with sound but also with electromagnetic waves, such as

Doppler Effect





light and radio waves. The frequency shift can be used to calculate the distance to stars, for example, as the color of the light changes due to the bunching up and spreading out of the waves. Radar speed traps also traditionally measure speeds using the Doppler technology.

What happens during an ultrasound scan?

Usually, the patient lies on an examination bed in a darkened room. The sonographer applies a water-based gel to either the skin or the transducer. This gel is a coupling agent that prevents the ultrasound waves from being reflected by air between the skin and the transducer. The sonographer then moves the transducer across the body, applying slight pressure, and can tilt the transducer to observe organs and structures from different angles. Occasionally, the patient is required to change position or to hold their breath for a short time during the scan.

In rare cases, the transducer is not moved over the skin but rather inserted into the body. This may produce a sharper or more accurate image of the organ, or it may be the only way to conduct the scan. Scans of this kind are performed using specially shaped transducers that are adapted to the various orifices of the body. The technical term for examinations of this kind is endocavity ultrasound.

Sometimes—for example, when metastases are suspected in the liver—a contrast agent is injected into the patient. Contrast agents consist of tiny gas-filled microbubbles that are approximately 10 times smaller than the diameter of a human hair. These microbubbles reflect the waves more strongly than the body tissue, enhancing the ultrasound signal to improve image quality.

Aristotle, bats, and the sinking of the Titanic



P. ATHANASIVS KIRCHERVS FVLDENSIS
ê Societ: Iesu Anno ætatis LIII.
Honoris et observantia: ætjò sculpsit et D.D. C. Bloemaert Romæ 2 Maij A. 1655.

Athanasius Kircher, “the last man who knew everything”

The history of ultrasound diagnostics began long before the first medical experiments—strictly speaking, in ancient Greece, at a time when poets and philosophers were searching for explanations of natural phenomena. Echoes, like many initially inexplicable phenomena, were incorporated into myths: The nymph known as Echo hid in rocky mountains and caves, secretly listening to people’s conversations and repeating their last words. Aristotle came closer to the truth with his scientific observations in the 4th century B.C. He explained that sound only occurred in ‘elastic objects’—that is, not in sponge or wool—and propagated through the air. Echoes, he said, were formed when “the air bounces back again like a ball.” Many of Aristotle’s explanations were so accurate that they would not be expanded upon significantly until 2000 years later.

In the 17th century, many scientists studied sound and its propagation, including one of the world’s greatest scholars at the time: Athanasius Kircher, described by one biographer as “the last man who knew everything”, experimented with the amplification of sound using pipes and measured sound reflection on city walls and in caves. Some of Kircher’s theories proved incorrect, but his experiments represented an important step toward understanding the phenomenon of the echo. He and his contemporaries knew nothing of ultrasound; research into this field essentially began with an

observation by the Italian universal scientist Lazzaro Spallanzani. In 1793, he studied bats and their mysterious ability to avoid even the tiniest obstacles in total darkness. Bats whose ears Spallanzani blocked with wax lost this ability. Although he correctly surmised that the animals were using sound for orientation, he was unable to explain or prove his hypothesis. Many scientists continued to debate Lazzaro Spallanzani’s theory for almost 150 years, and some even rejected it because no human ear could detect the animals’ calls. Bats emit impulses lasting for 0.01 to 0.02 seconds at a rate of 5 to 60 times a second and at an ultrasonic frequency of between 30,000 and 70,000 Hz. It was not until 1938 that technology allowed the sounds to be converted so that they were audible to humans: The American scientists Donald R. Griffin, George W. Pierce, and Robert Galambos used sensitive microphones and amplifiers to prove the sonic hypothesis and coined the term echolocation.

In the time between Lazzaro Spallanzani’s theory and the arrival of sensitive ultrasonic microphones, numerous discoveries and ingenious experiments took place that expanded our understanding of sound and made ultrasound technology possible. The Swiss physicist Jean-Daniel Colladon, for example, immersed a bell in Lake Geneva in 1826 and measured the speed of sound from a distance of almost 14 kilometers. The figure he obtained—1435 meters per second in water at a temperature

Christian Doppler discovered the effect that still bears his name today.

of 8 degrees Celsius—came very close to the actual modern value (1441 meters per second). Several years later, the Austrian mathematician Christian Doppler achieved fame when he discovered and predicted the effect that still bears his name. The first comprehensive and precise mathematical description of sound waves came courtesy of the English physicist and subsequent Nobel laureate John William Strutt, better known as Lord Rayleigh.

The theory was largely complete by the second half of the 19th century, but the technology was still in its infancy. The first instruments with a practical benefit included a whistle that could produce ultrasound. Francis Galton used his 1876 invention to study the hearing of humans and animals; today, it is known as the dog whistle. In 1880, a 21-year-old Pierre Curie and his brother Jacques discovered that quartz crystals emit an electrical voltage when they deform under pressure. Known as the piezoelectric effect, this phenomenon forms the basis for numerous pieces of technology, such as microphones, loudspeakers, and sensors, and for all modern ultrasound systems.

However, the piezoelectric effect went unused at first. The sinking of the Titanic on April 15, 1912, led to a huge surge in technical development: The German physicist Alexander Behm began seeking out methods for locating icebergs underwater while there was still time to react. Although Behm's





Cover of the
New York Herald
from April 16, 1912

echo-sounding system was unable to spot icebergs, as they barely reflect sound, it was ideal for determining the depth of water. During the First World War, several countries independently refined this technology to create sonar (sound navigation and ranging), primarily with a view to locating submarines. Soon afterwards, in Japan, this approach was used for spotting shoals of fish. The Russian scientist Sergei Sokolov helped ultrasound technology make its breakthrough on land. In 1929, he suggested using ultrasound to detect structural damage in metals and as a new type of microscope. Sokolov's idea formed the starting point for the development of nondestructive materials testing using ultrasound, which became an established technique around the world a few years later. This period also saw the emergence of the first ideas and studies in relation to its medical applications. During a discussion at Siemens' medical technology laboratory in February 1935, the question arose: Could ultrasound also be used in medicine? The company began conducting basic research and building its first devices, leading to the first milestone in the history of ultrasound technology from Siemens Healthineers: Reimar Pohlman's pioneering work on ultrasound therapy.

Using ultrasound to find structural damage in metals during the mid 1930's



“Like an airplane on a radar screen”:

The early years of medical ultrasound technology



“The Bible” of ultrasound, first published by the German physicist Ludwig Bergmann in 1937



Reimar Pohlman developed the therapeutic use of ultrasound

The origins of medical ultrasound were marked by rocky beginnings. For most innovations in medical technology, it is clear from the outset just how much potential they harbor and what help they can offer patients and physicians. Ultrasound was initially dismissed by some researchers as diagnostically

useless, while others thought it interesting, and some even considered it a panacea. The press reported sensational achievements, while experts engaged in often-heated discussions about the details of their examinations. It took many years before a solid scientific foundation was laid. One

of the first major building blocks was a book written in 1937 by German physicist and university professor Ludwig Bergmann outlining the current state of research in the field. “Der Ultraschall und seine Anwendung in Wissenschaft und Technik” (published in English under the title “Ultrasonics and Their Scientific and Technical Applications”) became a standard reference work and was for a long time considered “the bible of ultrasound.”

In the chapter on the medical benefits of ultrasound—which at that time was still very short—Bergmann cites the very first ultrasound generator developed by Siemens. The device was first tested in 1936 at University Hospital Erlangen’s gynecology department. According to a Siemens research report, it was equipped with everything “that might foreseeably be required for any medical applications of ultrasound.” After the publication of Bergmann’s book, Siemens was flooded with enquiries, as “among interested parties, there was a widespread belief that we were already producing these devices on an ongoing basis.” However, at that point the ultrasound generator was still the only one of its kind, as the technology was still being perfected, “not least because no medical experience with ultrasonics had yet been collected.” This state of affairs remained essentially unchanged until two years later, when German physician Reimar Pohlman first discovered the therapeutic properties of ultrasound.

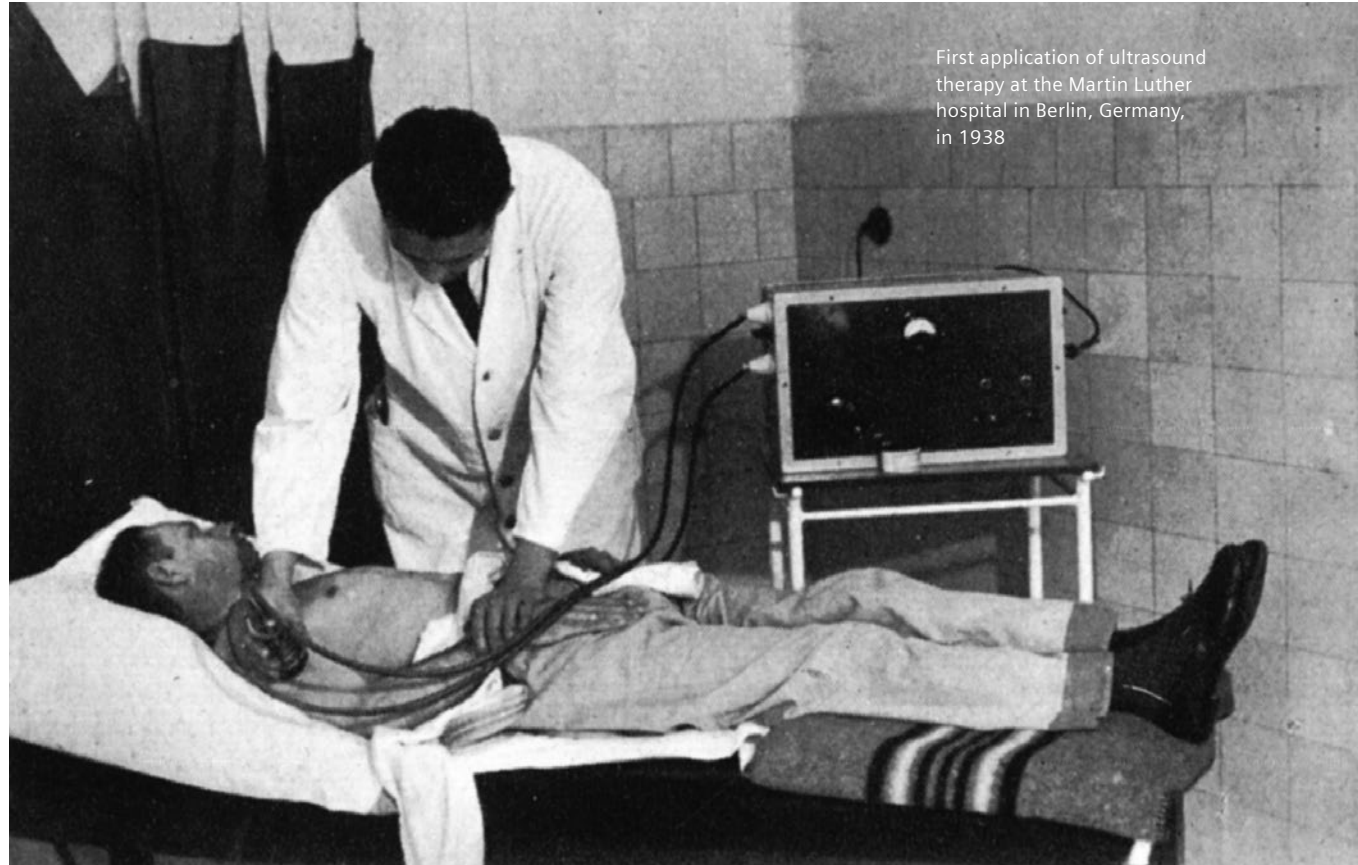
Healing vibrations and a sonic eye

When Reimar Pohlman began his experiments in 1938, research into the effects of ultrasonic waves on animals and humans was still at a rudimentary stage. Scientists in the USA, Germany, and Japan were primarily interested in how ultrasound behaved in the body at high frequencies. Yet, early therapeutic trials had failed to yield appreciable results. On reading their reports, Pohlman, who at that time was employed as an assistant at the University of Berlin's Institute of Physics and Chemistry, concluded that low frequencies had the effect of exciting body tissue and could therefore help heal certain illnesses. With this in mind, Pohlman set to work, measuring ultrasound absorption in different tissue types and searching for a frequency suited to therapeutic applications. Pohlman and his employees then verified their findings by conducting trials, first on themselves and later on patients at Berlin's Martin Luther Hospital. Even this early clinical trial enjoyed a remarkable success rate: 15 patients suffering from sciatica or rheumatism soon reported a "pleasant alleviation of their condition" and requested further treatment. After two weeks of ultrasound therapy, 10 patients were pain-free. Although the other five were not permanently healed, they too experienced considerable relief during treatment. It later transpired that the complaints of these five patients were not in fact caused by sciatica or rheumatism,

but by advanced joint deformities resulting from arthritis. Pohlman ascribed the soothing and healing effect of ultrasound to a kind of massage effect, in which the ultrasonic waves move the cells of the body, thereby stimulating them.

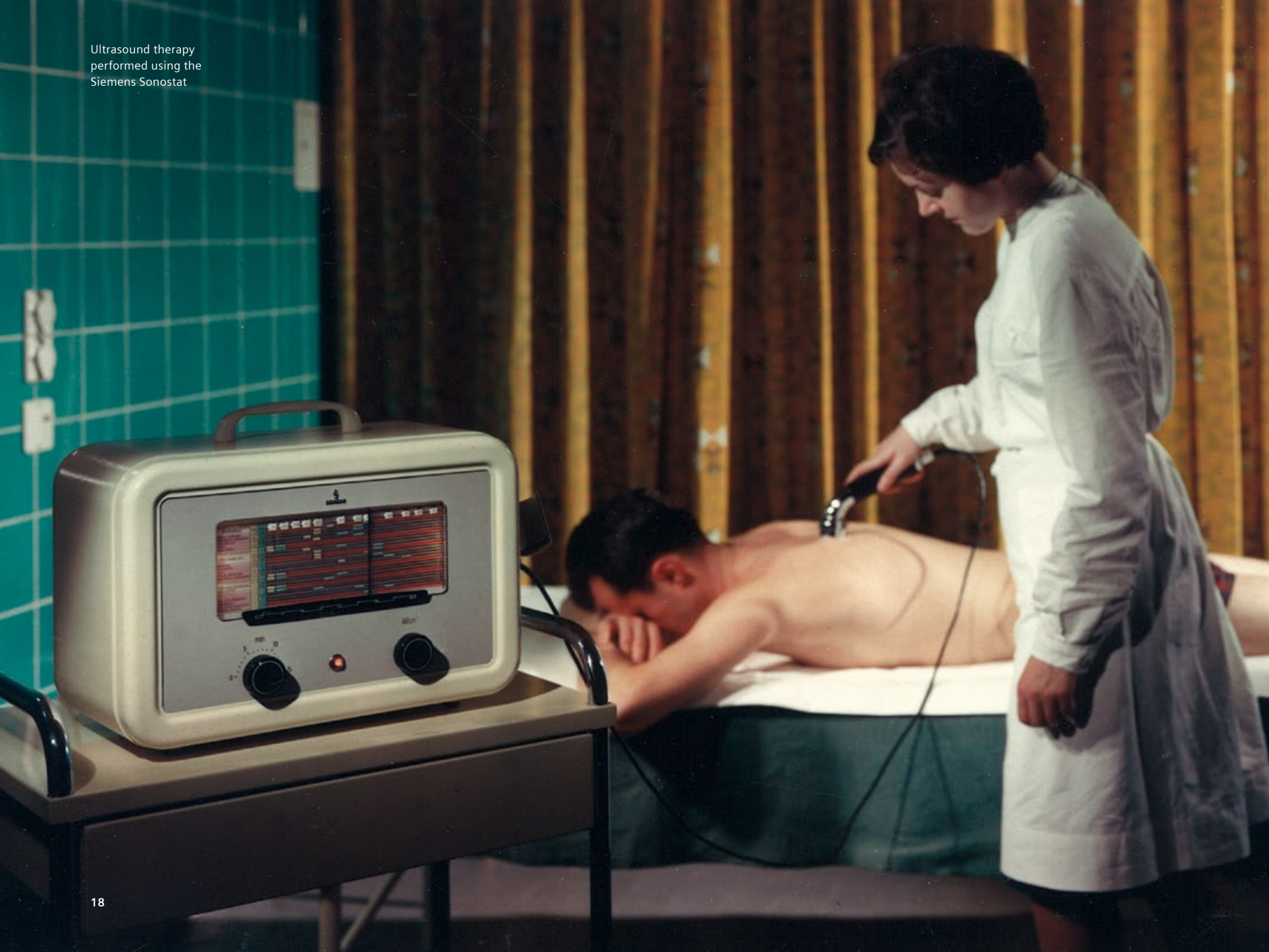
In 1939, Pohlman was assigned to head the new Siemens ultrasound laboratory in Berlin, where he continued to conduct research on the medical principles, while also working on a method to

examine the interior of materials using ultrasound. This led to the development of several ultrasound appliances based on various technological approaches and uses: Medical applications created in cooperation with his Siemens colleagues in Erlangen included the Sonostat ultrasound therapy unit, and for metals analysis he developed a 'sonic imaging procedure' able to detect minute manufacturing flaws in materials. A newspaper article heralded the 'sonic eye', anticipating the huge future



First application of ultrasound therapy at the Martin Luther hospital in Berlin, Germany, in 1938

Ultrasound therapy
performed using the
Siemens Sonostat



significance of the invention: "There can be no doubt that these sensational achievements ... will have an impact that cannot yet be foreseen today." While the repercussions of inventions such as these were impossible to predict at the time, Pohlman's work was just one of the first great milestones in the history of medical ultrasonics.

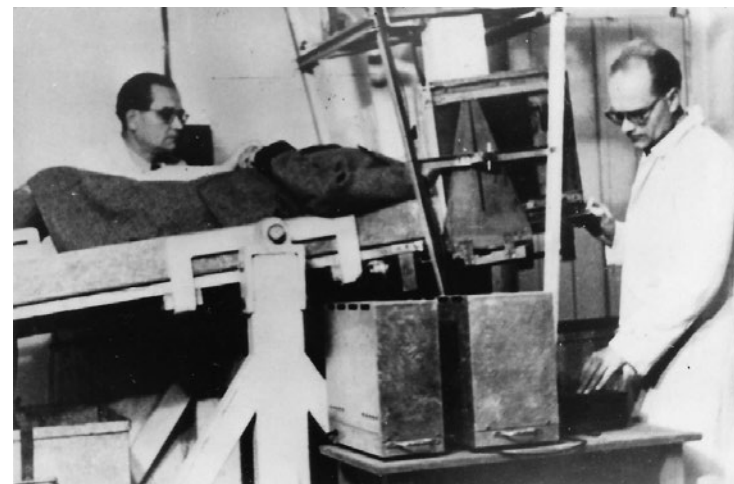
A first glimpse into the human body

In the late 1930s, Austrian neurologist Karl Theo Dussik read a short article reviewing the current state of ultrasound research. He was so captivated and intrigued by the technology and its possibilities that he began to take a serious interest in echolocation and materials testing. Studying the preliminary work done by Sokolov, Bergmann, Pohlman, and countless others, he recognized the technology's clinical potential and came up with "a plan to seek to exploit it for diagnostic purposes." In 1941, Dussik wrote an essay in which he described both in detail and in terms accessible to lay readers how ultrasound might be used in diagnostic applications. The paper concludes with the words "the readings thus obtained could be of practical value."

Dussik's findings were indeed of practical value, and his ideas included some of the key principles underlying ultrasound diagnosis. However, external conditions were anything but conducive to their practical implementation: In 1941, Dussik was drafted into military service to work as a doctor in a German Air Force hospital. At first, he was entirely reliant on his own resources to continue his experiments, having no financial support and exploring previously uncharted technical territory with his diagnostic apparatus. He sought assistance from his brother Friedrich, who as a physicist had some experience with another technological innovation, the television. After the war, they built

a contraption together which at first sight appeared quite grotesque. With the patient lying on a platform, the entire device would be tilted along with the subject, leaving them with their feet in the air and their head partially submerged in a water bath. Under the water, two opposing ultrasonic transducers rigidly attached to one another would revolve around the patient's head. One would emit the ultrasound waves, and the other would receive the attenuated signal after it had passed through the patient's skull, converting it into light to be recorded on photographic paper. This procedure resulted in the first ever ultrasound images of a human body, in 1947.

At around the same time, various leading ultrasound researchers decided to hold an ultrasound congress in 1949 bringing together a small circle of ultrasound specialists in the German town of Erlangen. Interest from physicists, biologists, and physicians was so great that this small circle eventually became a three-day conference attended by over 350 scientists. Many more were turned away due to a lack of space. In a lecture hall at Erlangen University, packed from morning until night, 72 speakers reported on the results of their research, although only a few of them dealt specifically with the field of medical diagnostics. One of these was Karl Dussik; another was the physician Wolf-Dieter Keidel, who was working alongside Siemens researchers on a procedure to monitor organ function with the help of ultrasound. However, diagnostic technology was still in its infancy at this point. Both Keidel's approach and that of the Dussik brothers relied on the transmission method, in which the ultrasound signal does not return to the probe as an echo, but rather passes



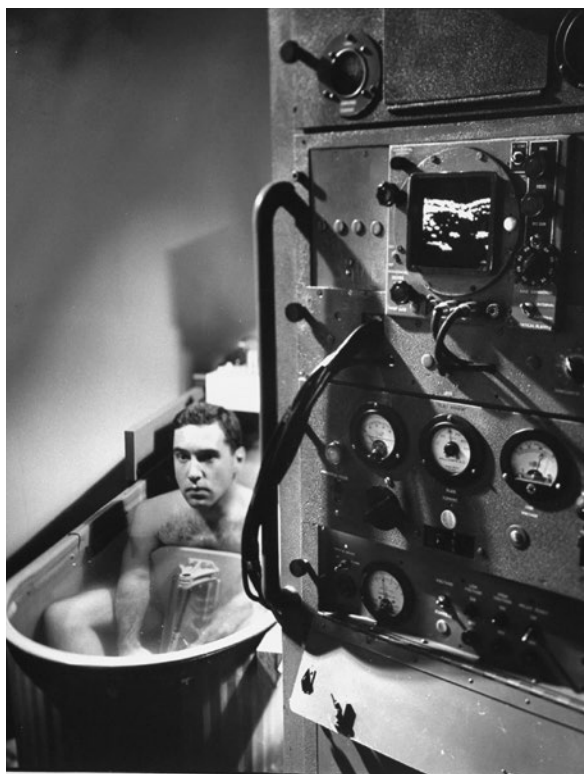
Benedict Cassen (L) and the rectilinear scanner

through the subject's body, to be received by a second transducer. This basic setup resembled that of an X-ray machine. It was not until after the Erlangen congress that research into ultrasound diagnostics began to gain momentum, motivated in part by the presentations given at the congress and in part by independently reached new ideas and insights.

From one-way transmission to echo detection

Soon after the congress, the Siemens electromedical laboratory in Erlangen began a close collaboration with the Dussik brothers. The primary goal of the exchange was to assess the potential for further developments. Siemens engineer Theodor Hüter, who had set out key principles governing the behavior of waves in the human body while working in the same lab as Reimar Pohlman, arrived at results similar to Dussik's. However, more accurate

measurements led him to a sobering conclusion: Dussik's images of the brain were not in fact faithful representations of its structure. The attenuation and scattering of the ultrasound signal caused by the patient's skull bone were so great that the resulting image was unusable due to the distortion. Moreover, Hüter concluded that further work on Dussik's procedure would not solve the problem. Nevertheless, the invention remains prominent in the history of ultrasound technology: Karl Theo Dussik was the first person to use ultrasound for medical diagnostic purposes, and his ideas laid the ground-work for a great deal of subsequent research.



A kidney examination with ultrasound in 1954

At this stage, the potential of ultrasound had already been acknowledged by numerous researchers; the issue now was finding the best technology with which to exploit this potential. Some of the most significant contributions in this regard include the first-ever medical application of the pulse-echo method: In 1949, U.S. surgeon George Ludwig unveiled a technique that allowed foreign objects in the human body to be displayed "as an echo, somewhat like an airplane on a radar screen." Ludwig used a modified ultrasonic materials-testing device, primarily to detect gallstones. This was remarkably successful. After just a few experiments, his method had reached around 85 percent accuracy, conclusively demonstrating the viability of the simplest form of echo imaging: the one-dimensional A-scan.



George Ludwig detects gallstones using ultrasound

Meanwhile, radiologist Douglass Howry hoped to build a device that could create "real images, similar to an X-ray scan or a photo-graph," in order to "distinguish between healthy and diseased tissue". Whereas a conventional X-ray image was unable to show subtle variations in soft tissue, ultrasound had the potential to reveal even the finest nuances. Like George Ludwig, Howry also sought to use echoes for this purpose. In order to eliminate 'false' echoes, Howry built a device with which the patient could be scanned from multiple directions by moving the ultrasound probe back and forth, an approach that became known as compound scanning. In the quest for the ideal scanner setup, a series of outlandish contraptions were tested over the course of several years.

Howry built the first incarnation of his idea in 1949 in his own basement, with the help of his wife Dorothy as well as the engineers Roderick Bliss and Gerald Posakony. A short time later, the group was joined by the doctor Joseph Holmes. The device consisted of replacement parts from radar systems,

an oscilloscope, and electronic components from a radio shop. The procedure was extremely uncomfortable, particularly when compared to modern systems: In the first prototype, the subject would sit in a barrel filled with water, replaced in subsequent versions by a cattle watering trough, and later a kind of giant metal pot. In 1954, the group created the first fully developed compound scanner in which the ultrasound probe revolved around a bathtub on a gear ring borrowed from the gun turret of a B-29 bomber. This setup provided the first genuine images of organs. Howry and Holmes used the device mainly to examine the liver, spleen, and kidneys, not, however, in actual patients, but rather in test subjects such as their engineer Gerald Posakony. The resulting images were still black and white, that is, without grayscaling to enable distinctions between different layers of tissue. Nevertheless, the group's creations are considered among the most important contributions to the development of the B-scan method.



Ultrasound exam conducted
in a bathtub in the mid 1950's

A honeymoon at Siemens

If, on your honeymoon, you tell your wife that you need to leave her for a while to do some work in an ultrasound research laboratory at Siemens, you really need to have a good reason. Fortunately for Carl Hellmuth Hertz, he had a very good one. Since 1952, Hertz and the cardiologist Inge Edler had been conducting research into the diagnosis of heart diseases at Lund University in Sweden. At that time, cardiac diagnosis was still in its infancy. Some diagnoses were based on nothing but discussions with the patient and what the physician heard through the stethoscope. If symptoms were more severe, the physician would also use a catheter or X-rays with contrast media to examine the patient. Some diseases were impossible or very difficult to detect with these methods, for instance, heart failure, which is when the heart valves do not close properly and thus allow blood to flow in the wrong direction. One of the tasks that Edler and Hertz set for themselves was to find a method that could reliably examine heart valve function while being gentle on the patient.

Edler wanted to build medical devices out of old military equipment from the Second World War. Hertz, a physicist, recognized immediately that old radar units were not suited to their needs, but he suspected that sonar technology had a great deal of potential. If ultrasound waves could locate submarines and steer torpedoes, surely they could also accurately visualize the rapid movements of the kind made by heart valves. In order to test his theory, he visited a shipyard in Malmö, Sweden, which used ultrasound to check welded seams on ships. Hertz held a transducer between his ribs, directing the waves at his heart. When he looked at the screen, he saw the echo of his heartbeat. In May 1953, he borrowed one of the ultrasound materials-testing

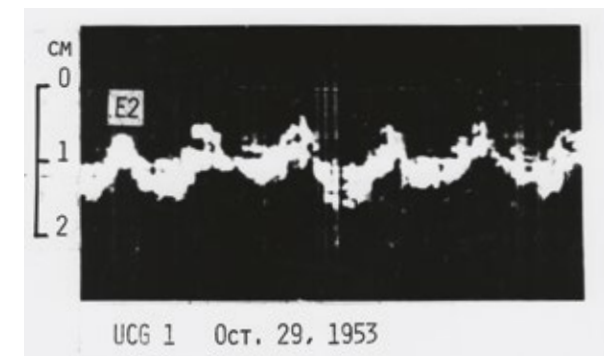
devices so that he and Edler could experiment with it. Unfortunately, the device was not suitable for advanced examinations. They needed an ultrasound device optimized for medical use, and Hertz's contacts at Siemens proved very helpful.

From 1935 to 1945, Hertz's father, Nobel laureate Gustav Hertz, had been head of a Siemens research laboratory founded especially for him. (Gustav's uncle Heinrich Hertz is equally renowned: The physical unit of frequency is named after him.) Hertz contacted Siemens and combined a visit to the medical technology division with a private occasion: A few weeks after he had watched his own heartbeat at the shipyard, he married. On their honeymoon in Germany, he left his wife alone for a few hours while he went to meet Siemens director Wolfgang Gellinek at the company's medical technology headquarters in Erlangen. Hertz borrowed a device that was equipped with a special camera that allowed the examination results to be stored and compared. Back in Sweden, he and Edler got to work at the university with a group of younger researchers. On October 29, 1953, they scanned echoes from the heart, first as A-mode signals. The camera then visualized the heart function as a curve, which was the invention of the M-mode and the first noninvasive representation of heart function in medical history.

In December, Edler and Hertz traveled to Erlangen to work with Siemens engineers on further improvements. Among other things, they optimized the device with "a field of view that only displays the medically interesting pulses," and with aids that helped physicians guide the transducer correctly. Edler and Hertz also received a specially designed transducer that could be inserted into the esophagus and thus enable even more-accurate examinations. From then on, Edler became almost inseparable

from the ultrasound device. He took it home with him on many weekends and on vacation to his summer house; he was even seen with it on Christmas Eve. His wife and four children supported him, sometimes serving as test subjects. His son Anders, for instance, allowed Edler to examine him at home with the esophagus transducer.

After two years of research, the results were substantiated to the point that Edler could rely on ultrasound diagnostics for various heart examinations. By 1956, the process was already so accurate that it detected a tumor in the left atrium of the heart. In 1958, a newly developed Siemens transducer made it possible to examine the structures of the heart. However, it was a few years before the process became established worldwide and took the name we know it by today: echocardiography. In recognition of their breakthrough, the two pioneers received numerous awards. For instance, Edler was voted Sweden's cardiologist of the 20th century, and he and Hertz both received the Lasker Award, which recognizes measures and programs that aim to improve human health and extend human life.



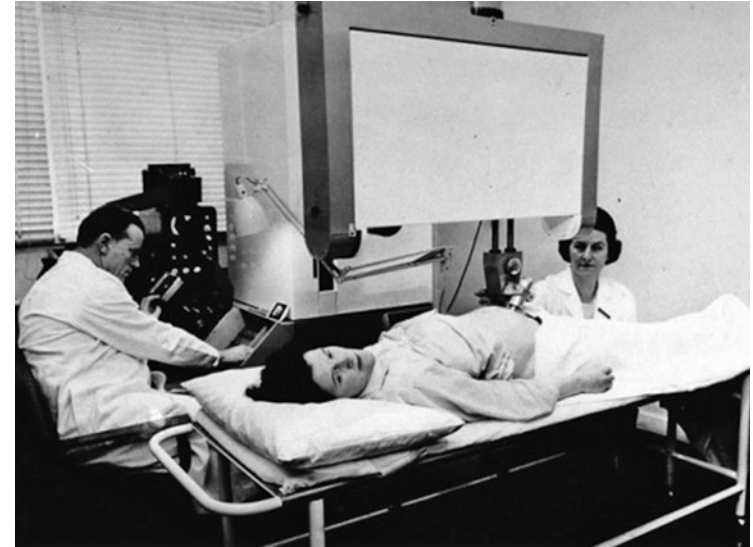
The first non-invasive visualization of cardiac function in medicine

Hertz (left) and Edler showcasing their first
"echocardiography" machine in the mid 1970's



Ian Donald's research
constituted a giant step
forward in the evolution
of ultrasound diagnostics





Ian Donald examines a patient in 1960

Professor prompts strange rumors

These accomplishments in cardiac imaging were followed by further breakthroughs in the field of ultrasound diagnostics. In 1956, English surgeon John Julian Wild reported on his examinations, in which he had diagnosed breast tumors with more than 90 percent accuracy using ultrasound. Around the same time, a Scottish professor of gynecology, Ian Donald, recognized the potential of ultrasound to allow a relatively comfortable examination of a part of the body that was uncharted territory for the obstetrics textbooks of the time: a pregnant woman's womb. In the mid-1950s, there was no way for physicians to look inside the womb and confirm a pregnancy before the 20th week. It was only after this point that the fetus could be detected by palpation, or its bones displayed on an X-ray image.

Ian Donald was intent on changing this and set to work, at first with only "a rudimentary knowledge of radar from my days in the RAF and a continuing childish interest in machines, electronic and otherwise."

To begin with, Donald also used a materials-testing device, employing the one-dimensional A-mode. He examined cysts and tumors recently removed by surgery, and verified his measurements using a large piece of steak. A short time later, the young engineer Tom Brown heard the "strange tale of a professor who was attempting to use a metal flaw detector to detect flaws in women" and offered Donald his assistance. Together, they built the first prototypes; the team then expanded and succeeded in producing the first contact compound scanner. The patient (or test subject, as was mostly the case at this stage) no

longer had to be immersed in water, as the transducer was applied directly to the skin. Over some 100 examinations, Donald was able to detect twin and triplet pregnancies, measure the heads of fetuses, and even save the life of one woman by diagnosing an easily removable ovarian cyst. Although the research carried out by Donald's team constituted a huge step forward in the evolution of ultrasound diagnostics, the devices they created were not really suited to everyday clinical practice, as operating them required a huge amount of time and extensive knowledge of physics. "Our findings are still of more academic interest than practical importance," Donald concluded in a paper published in 1958. This remained the case until a few years later, when an unconventional apparatus sparked the first great boom in ultrasound diagnostics: the Siemens Vidoson real-time scanner.

Images previously unseen by the human eye

Siemens Vidoson and the first boom in ultrasound diagnostics

In the summer of 1965, at Münster University Hospital, Siemens engineer Richard Soldner and head of his laboratory, Wolfgang Krause, put together a large and peculiar-looking contraption bearing only a passing resemblance to conventional medical technology. His curiosity aroused by the strange apparatus, the hospital's youngest resident physician, Hans-Jürgen Holländer, asked the two colleagues what it was. What he was looking at was the prototype of an ultrasound device able to visualize not just structures within a human body, but also their movements. At that point, no one could imagine the extent of the possibilities opened up by the Vidoson, but Holländer was to play a key role in discovering them. The original goal of the invention, which had been almost four-and-one-half years in the making, was to detect and more accurately diagnose breast tumors.

When the future of ultrasound diagnostics was discussed at a Siemens research conference on January 5, 1961, the procedure was still time-consuming, expensive, of little diagnostic value, and barely used in regular clinical practice. Ultrasound examinations were almost entirely restricted to compound technology: The ultrasound technician



Hans-Jürgen Holländer during his time as a resident physician at Münster university hospital

would pass the transducer, which was attached to a frame, multiple times across the relevant area of the body. The image was formed over the course of 1–2 minutes in a device known as a storage tube. Image defects were almost inevitable, as the slow scanning from different directions resulted in the superimposition of various

individual images. Furthermore, the images from inside the body were in black and white, without grayscale. To address these issues, the participants in the Siemens conference resolved to make "rapid image sequences" so as to be able to observe movement. Their goal: To create an ultrasound system with an output of 10 frames per second.

The young physicist Heinz Kresse was tasked with establishing whether such a device was even physically possible, and if so, how it could be built. To aid in his calculations, Kresse was given a state-of-the-art calculating machine. "It was electrically powered," he recalls 53 years later, "a marvelous thing!" As early as January 19, 1961, Kresse wrote in his notebook: "Found oscillating drive for transducer."

This completely novel construction, the ultrasound pendulum, oscillated back and forth 10 times per second, resulting in a scanning rate of 10 Hertz. Five months later, on June 26, Heinz Kresse used the oscillating drive to create the first-ever usable images of a beating heart. To this end, he took his own children Hans and Steffen with him to work, "because with children it is easier to get past the lung." The examination was a groundbreaking accomplishment, delivering the first-ever two-dimensional ultrasound image from inside the human body on a monitor, in motion, and without several minutes' delay—the birth of real-time imaging.

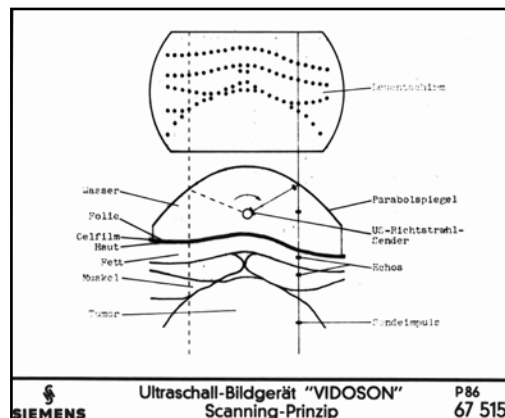
After laying these foundations, Kresse received engineering support from Richard Soldner, who was working on high-frequency technology in a Siemens basic research laboratory. Soldner adjusted the technology to meet practical requirements, added a few refinements, and built the first clinically viable prototype. At the heart of the device is a unique structure: the water-filled probe, with ultrasonic transducers rotating in the focal plane of a parabolic mirror. This mirror would concentrate the sound waves, reflecting them onto the foil on the lower side of the probe. As the transducers rotated, the ultrasound signal would move across the patient. In order to receive the echoes from the body, the transducer would switch to receive mode after each pulse. Each individual echo signal was represented on the screen as a dot, and the movement of the

transducers resulted in multiple dots to create an image. The cycle initially repeated at a rate of 10 times per second, which Kresse and Soldner soon increased to 16. This rapid image sequence allowed medical professionals to observe the inside of the body on-screen, as a true-to-scale moving image, in real time, complete with grayscale. All that was left was for the device to prove its worth in real-life conditions.

Skepticism and derision

The initial idea was to use the apparatus for breast examinations, as the rapid scan rate would in theory be excellently suited to this purpose: In just a few minutes, the entire breast area of a patient lying down could be examined by capturing numerous cross-sectional images that the physician could then evaluate on the spot. In the first clinical trial at Würzburg University Hospital's gynecology department in 1962, despite the fact that tissue changes were detected in many cases, the results were deemed unsatisfactory overall, as the image resolution was too low to allow conclusive findings. After conferring with medical professionals and his colleagues at Siemens, Soldner set to work on numerous improvements. In a second experimental model, operation was significantly more user- and patient-friendly, with the device no longer fixed to an examination table. Instead, the transducer could be freely swiveled on a repurposed X-ray stand, which would be moved up to the patient's bed on a platform. This was, arguably, the first-ever—if somewhat clunky—point-of-care ultrasound device.

Two subsequent clinical trials in the gynecology departments of Erlangen and Göttingen University Hospitals produced similar results: Insufficient resolution meant that other medical procedures were better-suited to the examinations in question.



Explaining the scanning principle of the Vidoson in 1967

Accordingly, the technology's creators were faced with a series of questions: Should development be halted altogether? Were there other clinical applications in which the unique device could play to its strengths? Might there even be disciplines in which the rapid image scanner could enable examinations not yet possible with any other form of medical technology? In 1964, physicians at Münster University Hospital were looking for ways to perform patient-friendly examinations of the female abdominal cavity using ultrasound. The hospital approached Siemens, and the following year, Krause and Soldner traveled to Münster to set up the device, where they were joined by Holländer. A short time later, he saw images that no one had ever seen before.

Initially, Hans-Jürgen Holländer reproduced the results obtained by the Scottish gynecologist Ian Donald and his Swedish research colleague Bertil Sundén in their work with compound scanners. He attempted, frequently assisted by his colleagues Paul Weiser and



Richard Soldner adapted the technology to meet practical requirements in his ultrasound lab at Siemens in the 1960's

his attending physician Dieter Hofmann, to use the Vidoson to detect tumors. Not only did he succeed in detecting contours, unexpectedly, even internal structures were visible, "and, in fact, far more so than in Sundén's images, who was not yet working with a storage tube." Nevertheless, many other clinicians at the hospital continued to regard the extraordinary device with skepticism or even derision. This changed when Holländer used the Vidoson to diagnose an ovarian tumor in an 81-year-old adipose patient that had evaded detection by any other contemporary medical procedure and could not be located by palpation, even under anesthesia.

"Breathtaking results"

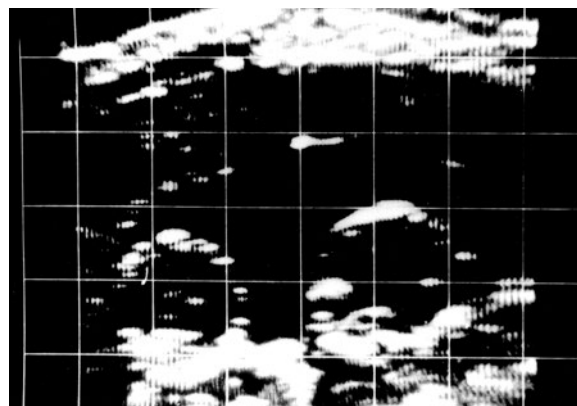
When tests began in mid-1965, childbirth was a process with little scope for medical planning, some-times holding great surprises for parents: Twin pregnancies, for example, were only detected before birth in about half of all cases. Other essential

information, such as the baby's position in the womb, could only be obtained by palpation or, in case of doubt, with an X-ray scan. Holländer used the Vidoson to examine patients from the fifth month of pregnancy, and soon concluded that "these questions can be answered with an ultrasound examination." At first, he was able to see the heads of fetuses. As he gained more experience, he could eventually make out their movements and heartbeat. "This opened up unprecedented diagnostic possibilities," he recounts. On one occasion he was approached by a colleague who performed amniocentesis on pregnant women with blood group incompatibility. In order to find a placenta-free spot for the puncture, he asked Holländer for a way to locate the placenta using ultrasound. This could not be done using a compound scanner due to its inability to show structures, but with the Vidoson it was a simple matter: "Once the question had been asked, we were able to find the placenta immediately, and we asked ourselves why we hadn't seen it before," Holländer wrote a few years later. From then on, ultrasound was used to accurately determine the position of the placenta before every amniocentesis or intrauterine blood transfusion performed at the women's hospital in Münster. This substantially increased the accuracy and safety of the procedure and enabled successful treatment of numerous fetuses.

"After we had achieved such stunning results in the second half of pregnancy, we began using the device more and more in the first half, too," Holländer recalls. In those days, for the first half of a pregnancy—that is up until week 20—the womb was, in Holländer's words, a "black hole": The expectant mother was not yet able to feel her child, and the obstetrician could not examine it. It was only after the 20th week, when the bones of the fetus begin to accumulate calcium, that the baby (or babies) would show up on an X-ray. However, the Siemens Vidoson enabled

Holländer and his colleagues to observe the movements and heartbeat of a fetus from week 12. As they became more experienced, it was even possible to detect the fetus as early as week 9, "although any sooner was difficult, as the movements are very slight indeed." Not long after that, they were able to measure the skull and abdominal circumference to within 2 millimeters, allowing doctors to determine the age and weight of the fetus much more accurately than ever before.

From this point on, obstetrics and gynecology were radically transformed by the Vidoson, and just through the work of Holländer and other gynecologists; a new perspective had been opened up to patients, as well. Holländer recalls their reactions: "When expectant mothers at the end of their first trimester actually see that there is a moving, living child inside them, this has a fundamental impact on their relationship with their baby." He remembers many of them laughing, rejoicing, or squealing with delight upon seeing their child for the first time on the Vidoson screen. As physicians grew more experienced, new applications and increasingly accurate diagnoses became possible, soon expanding into areas beyond gynecology or obstetrics. When



Ultrasound scan from 1965 showing the heads of twins

clinicians from other hospital departments heard about the successes achieved with the Vidoson, they would bring their patients to Holländer to examine their spleen or liver. "After just 120 examinations, the Vidoson had been widely acknowledged as a hugely important diagnostic tool in our hospital. It surpassed our expectations by far."

During the entire test period in Münster, comprising some 3500 examinations in all, Hans-Jürgen Holländer and his colleagues were in constant communication with Siemens, in particular with Richard Soldner. Their combined efforts led to refinements to support regular clinical use and simplify operation. At this point the device was still a prototype, and its peculiar construction made it susceptible to malfunctions. On one occasion, when a leak was detected in the transducer membrane, Holländer called Soldner, who got into his car, drove 480 km from Erlangen to Münster, installed a new membrane, topped up the water, and then drove back to Erlangen.

On June 7, 1966, the clinical trial period for Siemens' revolutionary Vidoson device came to an end, after which the prototype was to be collected from Münster and returned to Erlangen. A day earlier, Holländer took his pregnant wife Annerose with him to the hospital, and together they saw their youngest son's "little head". It was this potential for gentle instant imaging, with a medical value unrivaled by any other procedure available at the time, that convinced decision makers at Siemens to begin pilot production. The first model, completed in January 1967, went to Holländer and his colleagues in Münster. Holländer continued his research and in the years that followed published countless results and papers that were to have a transformative effect on the fields of obstetrics and gynecology. Once the Siemens Vidoson was launched on the market, the



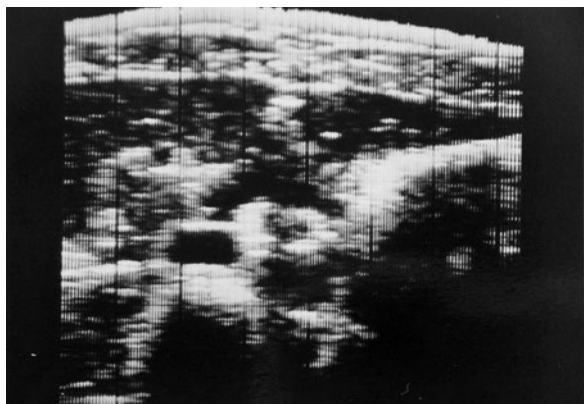
Ultrasound exam using the Vidoson in 1967

number of X-ray scans performed on pregnant women fell by around 90 percent in just a few years. The device was used to train gynecologists, and many of them went on to use the real-time scanner in their own medical practices. The field of gynecology and the Vidoson were jointly responsible for the first boom in ultrasound imaging. Not long after the market launch of real-time ultrasound machines, the new technology was embraced by another discipline: internal medicine.

Vital images

The physicians of antiquity already regarded the liver as one of the principal organs of the human body, believing it to be where feelings and sensations were experienced. Today, we know that the liver does indeed exert a great deal of influence on the entire body, as it plays a central role in our metabolic processes. The liver produces vital proteins, stores and converts energy sources such as glucose and vitamins, breaks down excess or harmful substances, and regulates the concentration of nutrients in the bloodstream. In the event of metabolic disturbances, close examination of the structure of the liver can assist diagnosis and help select the most appropriate treatment. However, in the mid-1960s, a liver examination was a very imprecise procedure. Doctors had to rely on palpation to examine the organ, which weighs between 1.5 and 2 kilograms and is located mostly below the ribs. At the time there was no medical technology they could turn to for support—or was there? Theoretically, the Vidoson should be capable of revealing even the liver's internal structure, as different types of tissue showed up as different shades of gray on the output images. To test this assumption, Siemens joined forces with the University Hospital Erlangen. This was how the internist Gerhard Rettenmaier began his research with the Siemens Vidoson, an undertaking that was to have a profound effect on his career and substantially expand the scope of ultrasound diagnostics.

Rettenmaier recalls his first encounter with ultra-sound technology as follows: When he was working as a scientific assistant for internal medicine in the mid-1960s, "a Siemens delegation paid a visit to my boss, Professor Demling, saying they had developed an imaging device for diagnosis in obstetrics, and asked whether we wanted to test it on organs such as the liver." Not long afterwards, Rettenmaier set to work. To begin with, he had to determine the best examination method for



Visualizing liver, pancreas, aorta and vena cava

the task. Which direction of the sound waves was best-suited to which clinical question? What was the best way to determine the liver's shape, or the density of the tissue? A crucial factor for many internal examinations was the way in which the Vidoson displayed the inside of the body—as a cross-sectional image, that is, as if the body were cut into individual layers. Aside from exotic procedures such as blurring tomography, images of this sort could then be obtained only with ultrasound. In one of his first reports, Rettenmaier writes: "Cross-sectional images make it easier—or indeed possible in the first place—for the physician to situate the area under examination and recognize morphological details." This was particularly relevant to the liver, but examination of the kidneys, spleen, and thyroid with the new ultra-sound technology also revealed previously hidden details. Of particular medical relevance was the Vidoson's ability not just to determine the size, shape, and position of organs, but also to reveal their internal structures for diagnostic purposes.

In 1967, the year of its official market launch, the Vidoson was deployed in a handful of women's

hospitals in Germany, including Tübingen, Frankfurt, and Munich. Siemens only built the device to order, in relatively small production runs. Then, Hans-Jürgen Holländer and Gerhard Rettenmaier separately shared their research results in numerous publications and lectures, pushing the novel technology toward a breakthrough. Siemens quickly shifted to serial production to keep up with demand. Holländer and Rettenmaier continued to play a central role in research into real-time ultrasound. In 1969 they met in Vienna at the first world congress on the use of ultrasound in medicine (although this was not its official name). During an exchange of views on the subject, they suddenly found themselves caught up in a discussion with other congress members that was to endure for several years, passionately at times: Which procedure was best-suited for the clinical practice—real-time or compound ultrasound?

A heated debate

At this point, the ultrasound community, known in German as the "Schallers" ("ultrasounders"), had polarized into two distinct camps. One side advocated the major advantage of compound scanning: It was able to image the entire abdomen in a single scan, whereas the Vidoson could only show sections of 14 centimeters in width. On the other side, the real-time camp emphasized the Vidoson's high imaging speed—of crucial importance to everyday clinical practice—and its ability to display different types of body tissue in shades of gray, a feature without which many diagnoses would not have been possible. Gerhard Rettenmaier became passionately involved in the debate. Possibly his best-known pronouncement on the issue was to call the absence of grayscale a "birth defect" of the compound scanner. In the field of gynecology, too, the issue was "at times the subject of vigorous debate in the years from 1968 to 1975," as Hans-Jürgen Holländer reports.

Ultimately, real-time technology prevailed. In the United States, however, the devices were not accepted before they became smaller, more manageable, and easier to operate. This was the result of a technological breakthrough resulting in a much smaller and more flexible transducer. The Vidoson's original transducer, with its complex mechanical setup comprising a drive unit and mirror optics, was replaced by the fully electronic scanning systems known as arrays, which can be found in every ultrasound system today. The very first linear array was tested by Richard Soldner and his colleague Gerhard Naefe in their laboratory as early as 1968. It consisted of 121 piezo elements arranged in a row, controllable in individual groups, a setup that essentially reflects that of current array technology. The same is true of the world's first annular array with dynamic focusing, developed by Siemens in 1971. However, both technologies turned out to be ahead of their time by a number of years. In the early 1970s, electronics were not yet sufficiently advanced to reliably control the new transducer technology and convert the signals into an image. As a result, the plans returned to the drawing board for quite some time.

A cowboy with an aquarium

Until the mid-1970s, the Siemens Vidoson remained the only mass-produced real-time system on the market. Then, in 1975, a representative of the company Advanced Diagnostic Research (ADR) attending the 2nd European Ultrasound Congress in Munich caused a stir by scanning in an aquarium using ultrasound to show the fish moving on the screen while he was dressed as an American cowboy. Equally remarkable was the transducer he used for his demonstration: a relatively compact linear array. The device, named ADR 2130, became the first commercially successful system with an electronic

transducer, boasting an image resolution that was truly impressive for its time. Siemens too substantially improved the resolution of subsequent models of the Vidoson—ironically, achieving results that were actually too good in the mid-1970s, because the mechanical system was too powerful for the physical properties of the water in the transducer. “The Vidoson 735 had such a high resolution that the particles in the water path were visible in the final image,” explained Paul Harbert, at the time a Siemens sales representative for ultrasound devices. “This is why the water had to be changed every few months, which involved 3 to 4 hours’ work each time.”

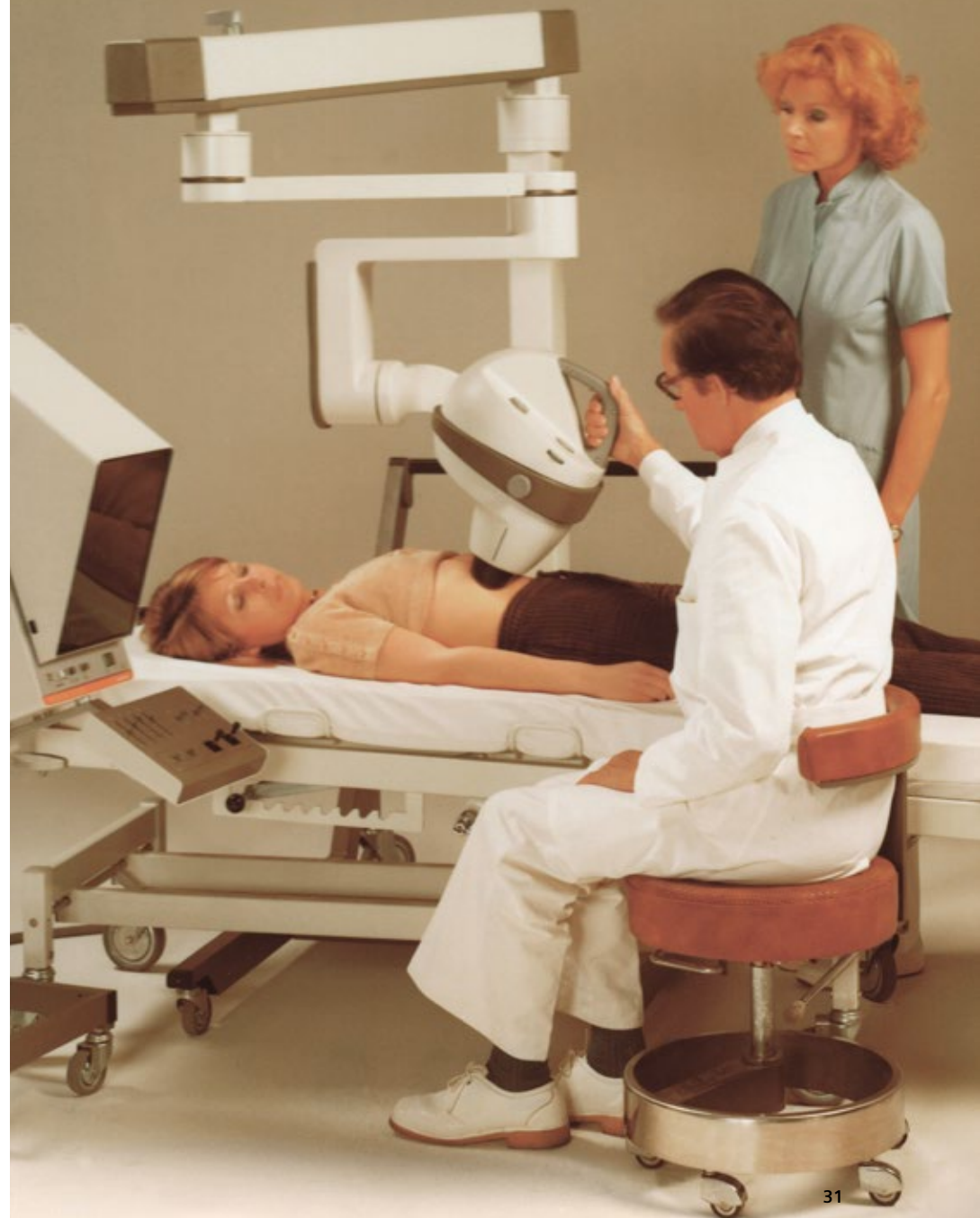
This meant that further improvement was impossible, as the water was indispensable to operation. The era of purely mechanical systems was coming to an end: Microelectronics were taking over more and more functions, making devices significantly more powerful and compact. This technological shift bore unimaginable opportunities for ultrasound diagnostics, as we shall see in the following chapters.

The times are changing

Ultrasound pioneers such as Holländer and Rettenmaier and Kresse and Soldner helped revolutionize ultrasound diagnostics from the mid-1960s onwards. Groundbreaking research, known mainly in expert circles, constantly opened up new applications, such as the work of Jürgen Gehrke, who used the Vidoson to create the first-ever three-dimensional grayscale images of an entire heart in 1973. Textbooks grew thicker, and many patients both large and small were examined for the first time using the new technology.

In the mid-1970s, a new era was dawning for ultrasound diagnostics. The technology was rapidly growing in complexity, and the development of new systems was becoming an increasingly elaborate task. The days of individual pioneers shaping the evolution of medical ultrasound were coming to an end, as companies invested in ever-larger research departments. A dedicated team at Siemens in Erlangen developed the world’s first fully digital ultrasound device, while a start-up company in California built a system that delivered images whose quality completely eclipsed anything offered by its competitors: the Acuson 128™ ultrasound system.

The Vidoson 735, an ultrasound machine too powerful for the physical properties of the water in the transducer



Giant leap into a new technological age



Brainstorming the future potential of ultrasound in the late 1970's

For any healthcare professional using ultrasound diagnostics or for the researchers and engineers who sought to advance ultrasound technology, the 1970s were an exciting time. While sonographers were still very much seen as mysterious lone wolves, research had already advanced to the point where ultrasound was an indispensable diagnostic tool for many healthcare professionals in areas such as cardiology, neurology, internal medicine, and gynecology. The growth in knowledge and understanding of ultrasound over the years was impressive, and this knowledge is still growing today. Testimony to this is the increase in the number of international publications on ultrasound imaging in obstetrics and gynecology, with 296 relevant scientific papers published in 1978 compared to a single paper in 1958.

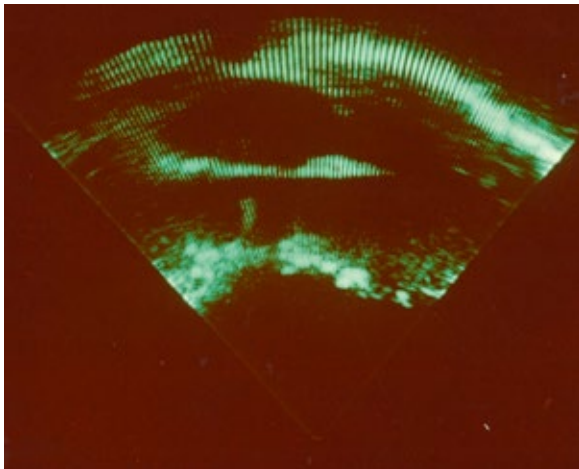
By the mid-1970s, the Siemens Vidoson was still the gold standard, the leading device on the European market. Even at this time, however, the technological approach that would lead to better-quality images and enhance diagnostic accuracy was already evident: electronic arrays, which had the potential to advance medical ultrasound imaging dramatically. Several compound systems such as the Vidoson, which produced grayscale images of body tissue, had come onto the market by then. Array systems, in contrast, not only delivered grayscale images in real time, but were also far more compact and user-friendly. Ultrasound technology was about to enter

a new generation. And this was true for more than just the development of ultrasonic transducers.

Microelectronics was changing the face of signal processing, and systems could now be controlled digitally as well as programmed to include a range of practical features. Back then, no one could predict what the ultrasound equipment of the future would be like. Various companies were taking different approaches in their development work. From 1975, Siemens made progress in its ultrasound development. A considerably larger team set about improving the Vidoson, exploring a host of new possibilities for the ultrasound technology of the future. A surviving flip chart from one of the team's sessions details all the possibilities they saw for ultrasound diagnostics in the years to come.

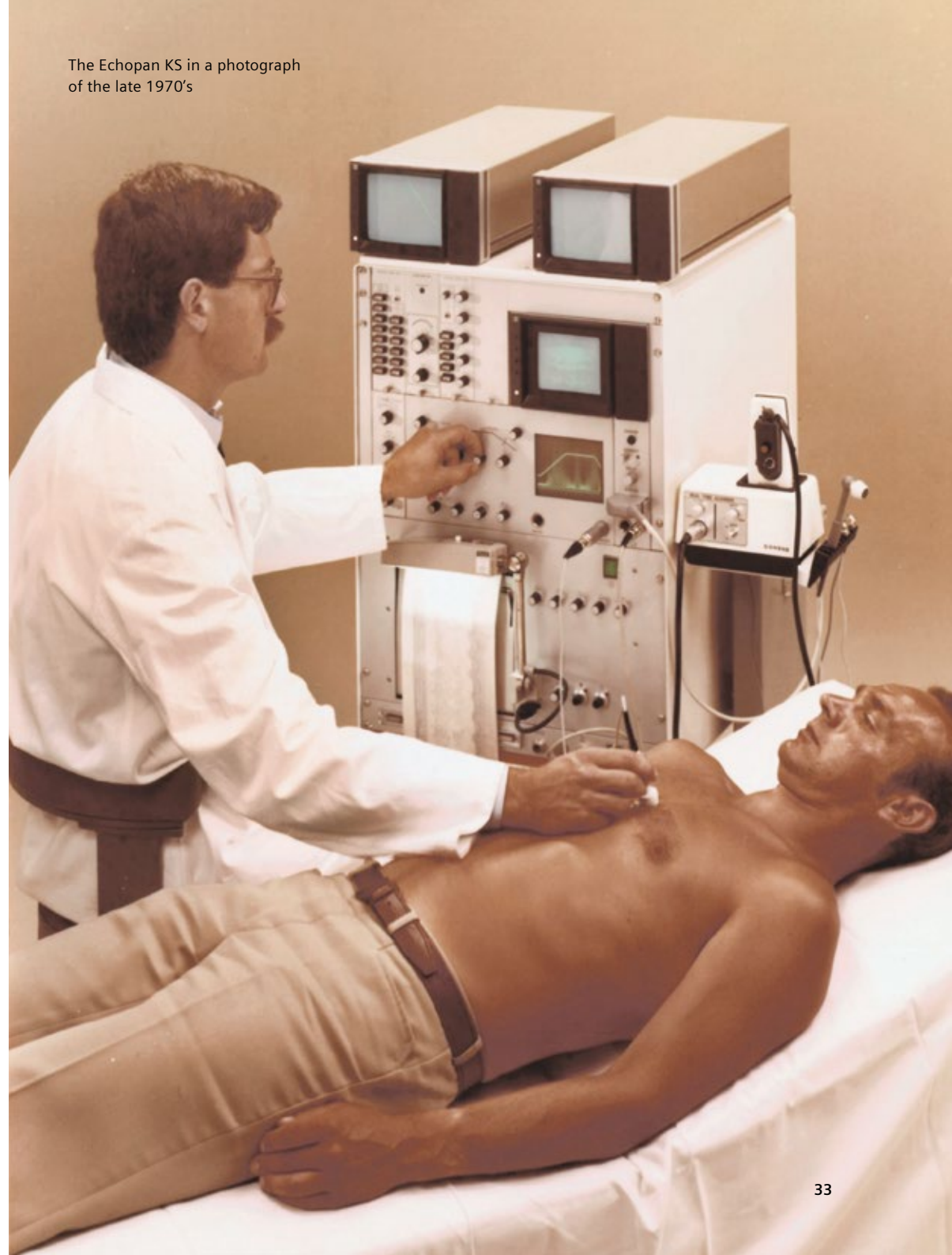
Within just a few months in 1977—with one brief interruption to celebrate 100 years of Siemens medical technology in Erlangen—the team at the ultrasound laboratory in Erlangen had developed the first-ever Siemens linear array scanner. The new system, the MULTISON 400, was a state-of-the-art device that operated at an impulse frequency of 4 kilohertz, delivering 40 images per second to the screen. Sonographers were now able to record the images obtained using a video recorder, with an automatic exposure control system adapting the image contrast to the film sensitivity.

The Echopan KS in a photograph of the late 1970's



Cardiac diagnosis using the Echopan KS in 1979

An echocardiography device that Siemens launched around the same time included similar features. This new device, the Echopan KS, included a mechanical sector scanner capable of producing images of the heart in real time and an integrated fiber optic UV recorder to transfer the echoes from the heart onto photographic paper. On request, the Echopan KS was also available with an integrated foil inkjet recorder rather than the UV recorder, the advantages being higher-contrast images that were less prone to fading. Physicians were able to pinpoint the precise section of the heart they wished to examine in B-mode and then switch to M-mode using a foot control.



The SONOLINE 8000, the world's
first digital ultrasound system



As expensive as a family home

For many experts, it had long been clear that digitalization was the next major step in the development of sonography. Microprocessors improved ultrasound technology in many different areas, from image quality to user-friendliness. Back then, U.S. pharmaceuticals corporation G.D. Searle & Company, or Searle as they were more commonly known, made what was probably the most advanced compound scanner at the time, driving forward digitalization. In 1976, Searle launched one of the first ultrasound systems to feature a microprocessor and digital scan converter. Microprocessors were managing signal processing control, among other things, and also calculated the scan results. The digital scan converter dramatically improved image quality, resulting in images with far more refined grayscale. In 1979, Searle sold its nuclear medicine and ultrasound business to Siemens following restructuring. Searle Ultrasound became Siemens Gammasonics, Incorporated.

In the same year, Siemens entered into a partnership with the U.S.-based company Dasonics for the purpose of marketing an extraordinary ultrasound

system—the Dasonics RA-1, a computer-controlled hybrid device composed of both a real-time and a compound scanner. In 1979, the RA-1 was the most powerful ultrasound scanner on the international market, but it was also the most expensive, costing as much as a single-family home. Thanks to the excellent image quality and ease of use, exorbitant price did not stand in the way of hugely successful market performance of the device. Due to its sensitive technology, however, setting up the machine proved difficult. A Dasonics RA-1 system required a complete quality check-up by a technician after its transport from the United States to Germany, for example, before it could go into operation.

During the glory days of the Dasonics RA-1, the Vidoson and the compound scanners disappeared from the market entirely, having been replaced by superior new-generation systems that combined linear array and real-time imaging. Siemens strove to improve and advance the technology of this generation, too, seeking new areas of application and pursuing many different, highly promising approaches. One of the most remarkable developments around 1980 was the Sonoline 8000.

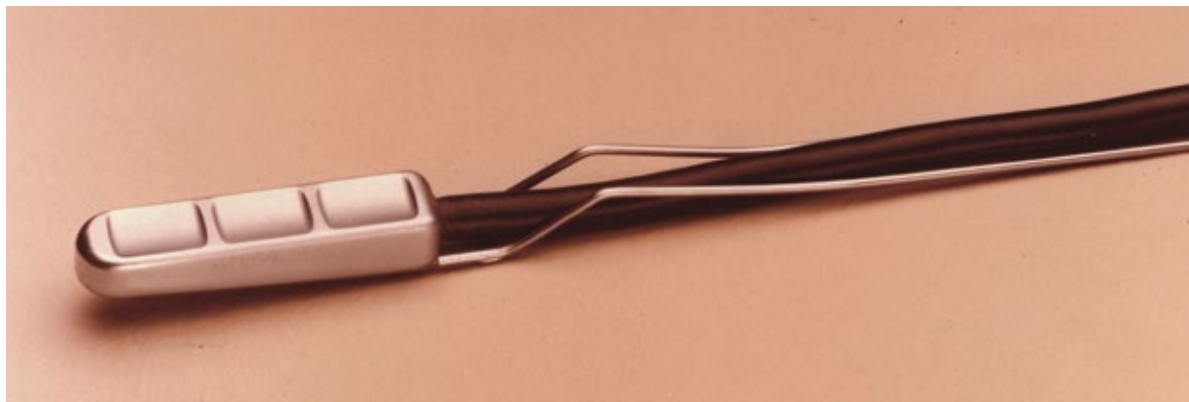
Video cassette versus DVD

In 1981, the Sonoline 8000 represented a huge technological leap. This entirely new type of ultrasound device was the first all-digital system: The device amplified the echo from the body, converting the amplified analog signals directly into digital signals. The difference between analog and digital images is something that anyone who can remember the vast difference in quality between the analog video cassette and the digital DVD will tell you. Digital images are stable and (virtually) noise-free, making them far clearer than analog images. While analog examination results are hard to transfer to a photograph or film, digital data can be saved without any loss in image quality and edited if required.

Starting in 1982, Siemens launched a series of specialized transducers: a breast examination device in which the transducer moves around the breast, taking real-time images from all directions, and various miniature transducers used to examine body cavities, for example, a transurethral transducer that is moved over the urethra to the bladder. Some years later the first vaginal probe was developed. Such body cavity transducers give physicians clearer images of the inside of the body than a scan taken from the outside through the skin would produce.

Old idea, new take

Impressive ultrasound images in amazingly high resolution are the product of a long-term research project between Siemens, the researchers from the Stanford Research Institute (SRI), the Department of Orthopedics at the University of Münster, and the Institute for High-Frequency Engineering of the University of Erlangen. The ultrasound transmission camera is similar in structure to the first ultrasound machine developed by Karl Theo Dussik in the 1940s:



Specialty transducer for use in surgery

The part of the body to be examined is immersed in a water tank, and ultrasound penetrates it and is detected behind the patient. Physicist Philip S. Green from SRI took up this approach in the early 1970s, improving on it substantially. Green's innovation was based on one-dimensional receiver rays. In the new research project involving Siemens, a transmission camera that produced two-dimensional pictures in real time was developed between the years 1979 and 1988.

The resulting images may not have lived up to expectations, but the device produced spectacular scans in previously unseen quality, depending on which part of the body the researchers were

scanning. Images of the abdominal area, for example, were very hard to interpret. In contrast, the transmission camera did a very good job of visualizing even the tiniest of structures and movements in the extremities. If the patient moved a finger, for example, the physician was able to see the interaction between ligaments, tendons, and bone more clearly than with any other method. For certain examinations, the transmission camera may well have become the technology of the future, were it not for two unsolvable problems: First, there was no way of moving the transducer over the patient's body precisely enough. Second, water was needed as a transmission medium. This made medical examinations too costly and time-consuming, since

the water tank had to be cleaned and refilled for each new patient. While the transmission camera was great for research purposes, when it came to clinical routine, scanners—now tried and tested devices—proved far superior.

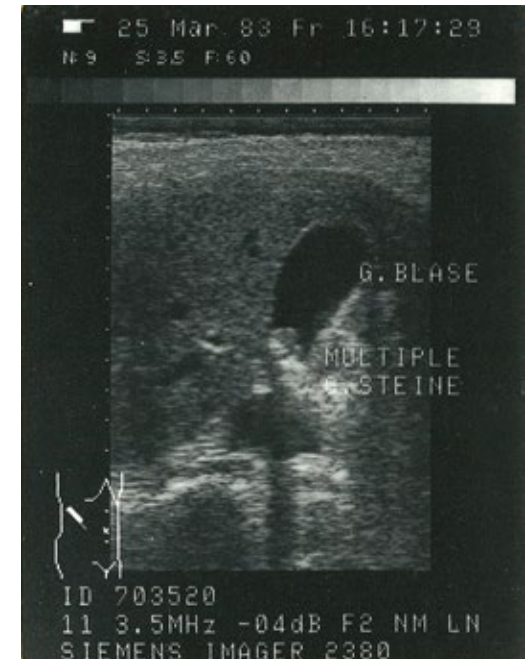
From the early 1980s onward, Siemens worked continually on expanding and developing new real-time array ultrasound scanners. Other new systems joined the high-end Sonoline 8000 on the market. Sonoline became the name of the Siemens ultrasound product family, remaining the mainstay of Siemens ultrasound technology for almost 25 years. The first few devices in the product family included the Sonoline 1000, a portable device weighing just



Imaging a finger with an ultrasound transmission camera



The SONOLINE 1000 was the first portable ultrasound system from Siemens



Visualization of gall stones using the Imager 2380

The SONOLINE SL, promotional
photography from 1984



10 kg that was used mainly in obstetrics, and the Sonoline 3000 sector scanner, which was especially suitable for pediatrics and internal medicine thanks to the small transducer contact surface. Following a distribution agreement between Japanese electronics firm Matsushita and Searle Ultrasound, the portfolio was expanded to include compact, powerful Japanese systems marketed under the name Imager, for example the Imager 2380, which could calculate the estimated due date in obstetrics automatically. From 1981 on, Siemens and Matsushita developed a number of new ultrasound systems such as the all-round system Sonoline SL, which could deliver both linear array and sector images of blood vessels and organs.



Pediatric hip examination of an infant at the Pediatric Clinic in
Erlangen, April 22, 1984

Incredible images by Acuson

In 1983, an ultrasound device was introduced that would cause great excitement in the ultrasound world. The Acuson 128, the first-ever ultrasound device made by the small, as yet unknown firm Acuson, surpassed all other ultrasound devices on the market at this time. The response of contemporary Siemens witnesses to the new device went along the lines of "Acuson has dared to make what others have only dreamed of", "Incredible images!", and "These guys took the lead worldwide—no question."

Acuson's story began a decade earlier. In the early 1970s, Samuel H. Maslak studied electrical engineering at the Massachusetts Institute of Technology (MIT). His wife was pregnant with their second child and underwent prenatal ultrasound exams. Maslak was fascinated by the technology, yet was quick to see the huge untapped potential in ultrasound



The first work bench at Acuson in Mountain View, California



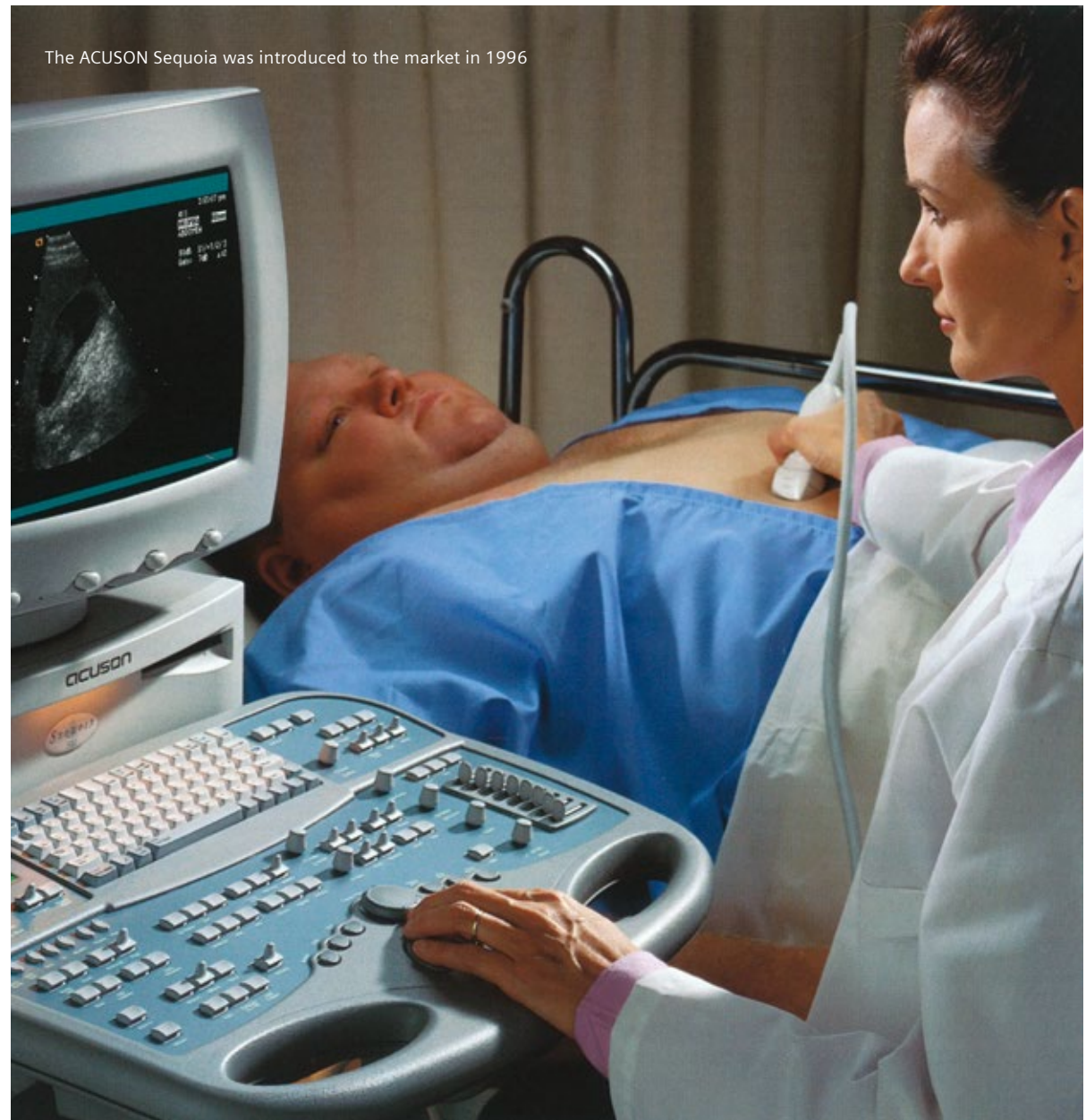
The ACUSON 128 excited the world of ultrasound in 1983

imaging. Maslak wrote his thesis on ultrasound technology, completing his studies at MIT in 1975 and starting a job as developer and project manager at Hewlett-Packard Laboratories, where he developed hardware and software for ultrasonic diagnostic systems, including a new, unique system architecture and focusing algorithms for ultrasound imaging. After just four years, he left Hewlett-Packard and began independent research into ultrasound diagnostics. At the outset, Maslak financed his research with a part-time job as a technical advisor. In 1981, Maslak went on to co-found the Acuson Corporation in Mountain View, California, with his former Hewlett-Packard co-workers Robert Younge and Amin Hanafy. Over the course of the next few years, other ultrasound specialists joined the team. Then, in 1983, the Acuson 128 was introduced to the ultrasound market.

At the time of its launch, the Acuson 128 cost twice as much as other high-end systems. The device was well worth the investment, however, delivering two to three times the detail in its clinical images. Scans were faster and more precise, saving time and costs. But what made this device superior to all the others? There were several technical reasons, but the main differentiator was the system architecture of the new device. While other ultrasound machines at this time had between four and six channels to process ultrasound signals, the first Acuson system had 128 independent software-controlled channels. For the first time, ultrasound imaging was computer-controlled and image optimization was software-based. The two-dimensional image could be enlarged and visualized in real time. Acuson themselves called the new technology computed sonography.

The Acuson 128 was a success from the very start, and by 1985 the company was the market leader in the United States. The Acuson 128 became the gold standard in an increasing number of applications, such as blood flow diagnostics, gynecology, and internal medicine. Later, it was also used in cardiology, after dedicated programs and Doppler functions had been incorporated into the device in 1985 and color Doppler added two years later. In 1990, the second generation, the ACUSON 128XP™ ultrasound system, was launched, which included a range of new technological features, such as Acuson's proprietary Vector Array Format Technology. This technology was able to produce a larger field of view so that more of a patient's anatomy could be visualized on-screen than had been possible with sector transducers.

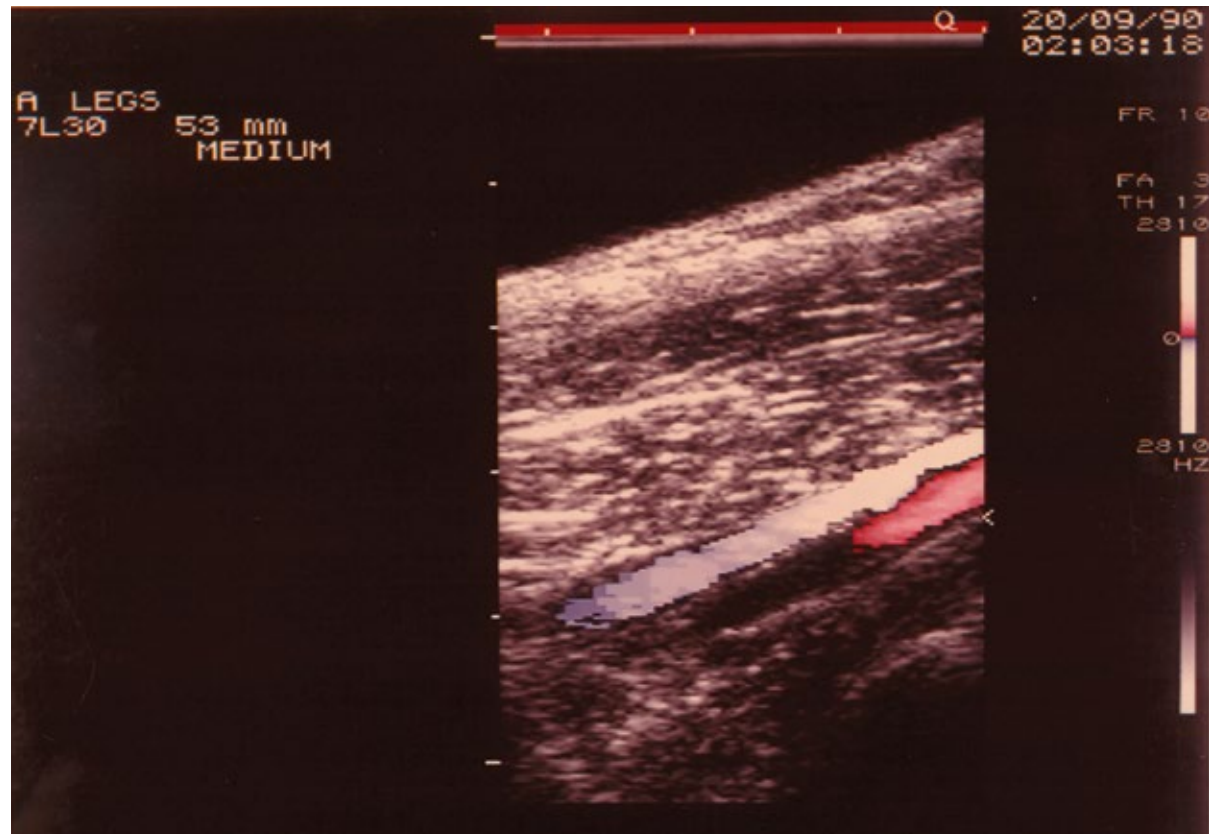
In 1992, Acuson launched the image and data management system AEGIS, which could be used to save and analyze scanned images on a PC. In 1996, this was followed by a device that for the first time used all the information in an echo for image processing. While conventional devices generated images from the frequency of the ultrasound waves, the new ACUSON Sequoia™ ultrasound system also utilized the distance between the waves. At this point, Acuson was focusing increasingly on applications for cardiology. In a move to expand this field, Acuson bought the Pennsylvania-based start-up company Ecton in 1999, which specialized in the development of portable echocardiography systems. Under the umbrella of Acuson, Ecton worked on the development of ultrasound technology that would, quite literally, reach the highest heights. More on this in the next chapter.



Blood flow diagnosis using an ultrafast computer

Meanwhile at Siemens, much had happened. Taking the leap into the digital age, Siemens developed a range of new hardware and software technologies and expanded its ultrasound segment with the takeover of Quantum Medical Systems, an innovative manufacturer of high-end devices specializing in the diagnosis of blood flow. As of 1990, Quantum, whose corporate headquarters was in Issaquah, Washington, was owned by Siemens.

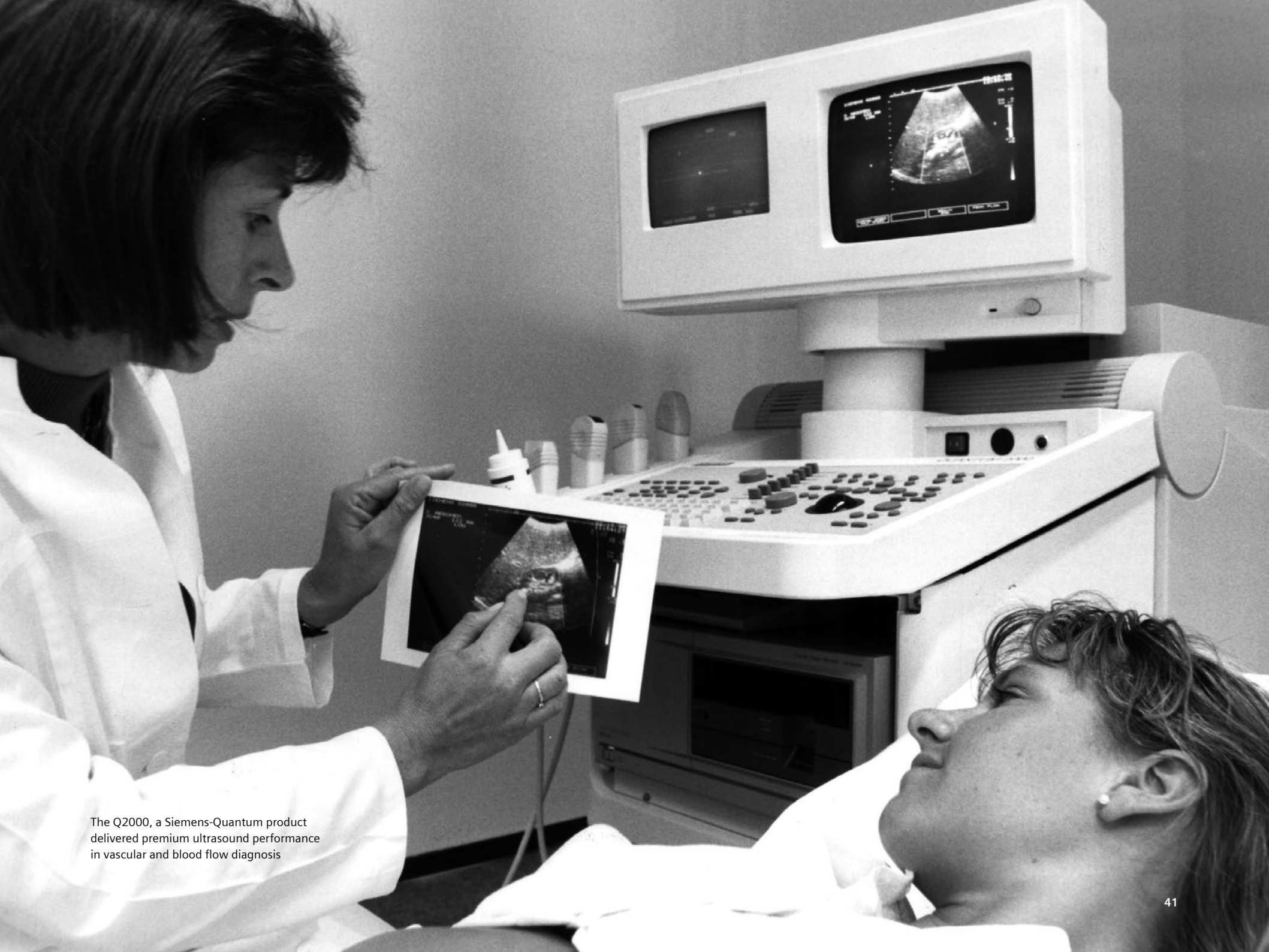
From the very start, Quantum, which was founded in 1983 by former ATL Technology engineers, specialized in the development of real-time color Doppler imaging systems. Until the mid-1980s, medical examinations of blood vessels had commonly used X-rays and contrast agents. The first Quantum system from 1986, the QAD-1, produced real-time moving images in color on a computer screen. Tissue structure was represented in grayscale and blood flow in red or blue, depending on the direction of flow. These images helped physicians understand the influence of tissue anatomy on blood flow to detect vascular constrictions. The QAD-1 used a combined technology known as duplex sonography which made use of the Doppler effect and did not need contrast agents.



Color Doppler imaging in 1991

Quantum called its new technology AngioDynography. Although the name failed to catch on, the new process spread rapidly in the years to follow. In 1991, Siemens-Quantum launched the Q2000, a premium ultrasound system for blood flow diagnosis. At the heart of the new color Doppler system was a processor able to calculate the diagnostic image at

a rate of 500 million calculations per second. At the time, this was in fact an “ultra-fast computer”, as described in a press release issued on the occasion of its launch. In 1992, Siemens moved its technical resources for the development of ultrasound systems to Issaquah, which then became the main global headquarters of Siemens-Quantum.



The Q2000, a Siemens-Quantum product delivered premium ultrasound performance in vascular and blood flow diagnosis

On the road to the next century

Siemens continued to expand the Sonoline family, producing specialized transducers and developing software for a host of applications. In the 1990s, the product portfolio contained the Sonoline CF, a color Doppler imaging device for echocardiography, a rectal transducer that aided in the diagnosis and treatment of prostate conditions, and the Sonoline Prima, which featured numerous user-friendly, time-saving settings. By now, software was becoming increasingly important. By the mid-1990s, the introduction of a picture archiving and communication system for ultrasound, the SonoPACS, allowed sonographers and physicians to analyze, diagnose, and save ultrasound examination results onto PC workstations. If required, the images could also be saved as TIFF files onto 3½-inch floppy disks.

At the 1995 meeting of the Radiological Society of North America (RSNA), Siemens unveiled its latest

premium ultrasound model, the SONOLINE Elegra™ ultrasound system which included more than 50 patented Siemens technologies. The computer-aided conversion technology in the transducer was capable of simultaneously processing all the signals received by 256 piezo elements. Each of the two signal processors in the SONOLINE Elegra system could perform 4 million calculations per second, exceeding the capabilities of PC processors at that time many times over. The ultra-fast signal processing suppressed motion artifacts so that particularly slow-flowing blood could be seen even in the tiniest of vessels. The platform concept behind the SONOLINE Elegra system meant that future, entirely novel applications could be added via a software update.

Such application extensions via software included SieScape™ panoramic imaging and 3-Scape™ real-time 3D imaging. Released in 1996, SieScape imaging enabled users to view up to 60-cm-long images of anatomical structures and organs on

screen in real time. By converting ultrasound signals into three-dimensional images, 3-Scape imaging helped physicians to identify complex structures more easily. In some cases, volume imaging delivered greater diagnostic detail than 2D ultrasound images, for example, when scanning the umbilical cord or the face of a fetus. Sonographers were able to view body structures from any direction while the examination was being performed, since the image could be rotated on-screen in real time. In internal medicine, 3-Scape imaging was instrumental in determining the success of chemotherapy on liver and intestinal tumors. These ultrasound applications did not need new transducers or other new hardware; all the necessary functions could be integrated via software updates into the SONOLINE Elegra system user interface.

At the turn of the century, ultrasound was indispensable in many fields of medicine. Progress in technology, particularly in the previous 20 years, made



The SONOLINE CF was one of the first echocardiography systems to feature color Doppler functionality



Faster than a personal computer: the SONOLINE Elegra



SieScape panoramic imaging of a kidney, 1996



Comparing a photograph and a prenatal 3D ultrasound image

many new applications possible. Ultrasound scans were quick, cost-efficient, and produced conclusive diagnostic results. For many medical problems, ultrasound was the imaging technology of choice. Back then, physicians at University Hospital Erlangen used ultrasound systems for more than 13,000 examinations of the gastrointestinal tract. In 1998, the Gastroenterology Department of the university hospital was also the recipient of the 1000th Sonoline Elegra ultrasound system. By then, the device had been enhanced to include additional features such as a new and improved Doppler function known as power Doppler. Developments in ultrasound technology were not nearly at an end. In the early years of the new millennium, Siemens developed several unique ultrasound technologies, some groundbreaking, such as the smallest ultrasound device in the world, the Acuson P10™ ultrasound system. As the name suggests, the system was a brainchild of both Siemens and Acuson engineers.

Ultrasound diagnostics in the new millennium

Over the course of three decades, ultrasound diagnostics evolved from an exotic and often-derided modality to one of the most widely used imaging techniques in medicine. Just about everyone had some experience with the technology. In Germany, it became standard practice to perform two ultrasound examinations during pregnancy from the 1980s onward; in 1996, the total number of examinations reported by German health insurance companies surpassed 35 million for the first time, and continued to rise. Advances in electronics and signal processing led to an ever-wider range of applications of increasing diagnostic value. At the turn of the millennium, the technology acquired

new momentum with the advent of digitalization. Soon, as we will see in this chapter, physicians could use small, compact ultrasound systems directly at the point of care, the site of an accident, or even on the world's highest mountains.

A closer examination of the hardware and software of ultrasound systems reveals that there is no universal technology common to them all. Different companies adopt different approaches that are related, but nevertheless optimized in different ways to suit particular purposes. Furthermore, each area of application calls for its own technological approach, as not all basic technologies are best-

suited to a given task. Cardiac examinations are not subject to the same constraints as abdominal ones, for instance. That said, from time to time there are technological milestones that are decisive in the development of ultrasound technology overall. One such example was computed sonography, forever to be connected with the Acuson 128 ultrasound system.

During the 1990s, Siemens and Acuson followed different approaches, resulting in different strengths. Siemens became particularly good at developing new technologies and applications, while Acuson built systems offering exceptional image quality, primarily for cardiology and vascular applications. Siemens enjoyed a strong presence in the ultrasound market outside of the USA, while Acuson was very well-positioned there. The two companies were ideally suited to a merger. In the words of the then-CEO of the Siemens Medical Engineering division, Professor Erich R. Reinhardt: "The combined product range of the two companies covers the entire market for ultrasound systems and computer-assisted network solutions, from portable ultrasound devices to high-end imaging platforms."

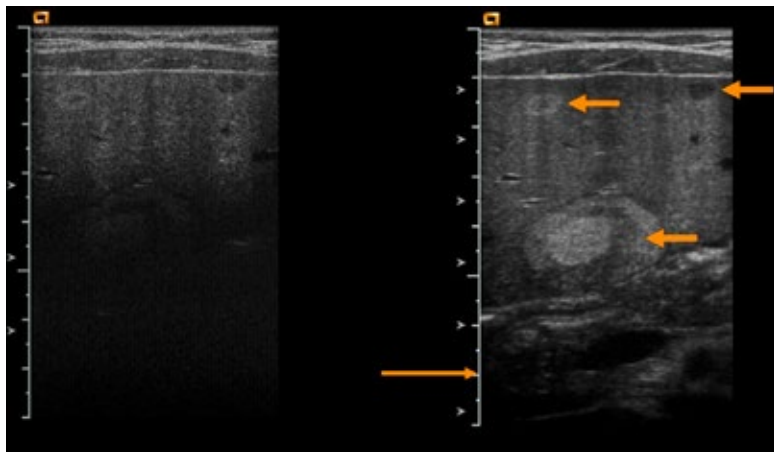
One of the main reasons for Siemens' interest in Acuson was their Sequoia flagship system, launched in 1996. The ACUSON Sequoia system was a technological masterpiece. At the turn of the millennium, this ultra-premium system was considered the



Power Doppler imaging of a kidney, 1996



The ACUSON Sequoia ultrasound system in 2006



A standard ultrasound image in comparison with an image acquired using the Hanafy lens technology in 2001



The headquarters of Siemens Ultrasound located in Mountain View, California until 2020

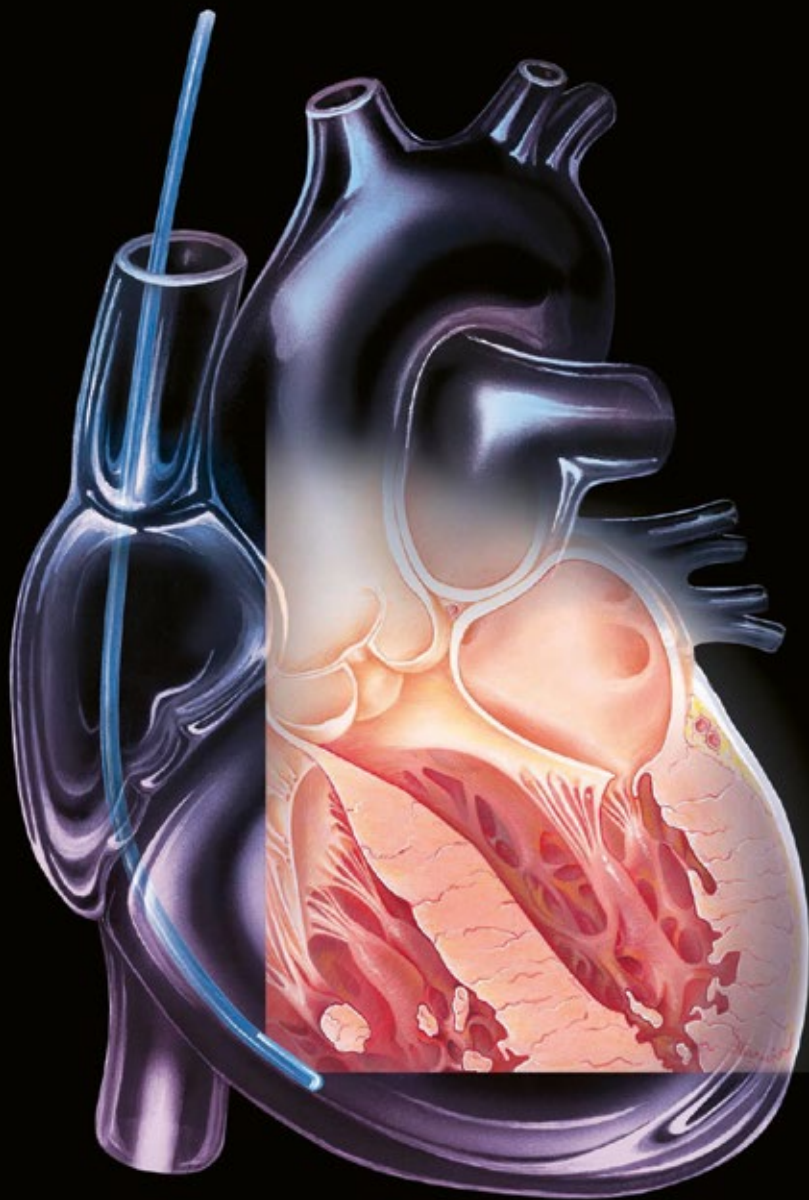
unrivaled gold standard in ultrasound diagnosis, an opinion still held today by some of its users. The outstanding image quality delivered by the ACUSON Sequoia system was enabled by various groundbreaking innovations, including Sequoia proprietary Coherent Image Formation and Hanafy lens transducer technologies. Sequoia proprietary Coherent Image Formation technology generates image data from the frequency of ultrasound waves, and the ACUSON Sequoia was the first—and at the time, only—system to use the distance between the waves as well. The system was able to process a much greater portion of the echo signals than conventional ultrasound systems, resulting in more-detailed, higher-resolution clinical images. Hanafy lens transducer technology featured a transducer design with a particularly delicate arrangement of piezo elements able to deliver high-resolution, uniform images even from deep tissue layers. The pioneering technologies used in the

ACUSON Sequoia system were perfectly suited to Siemens' mission of providing its customers with cutting-edge technologies at all times.

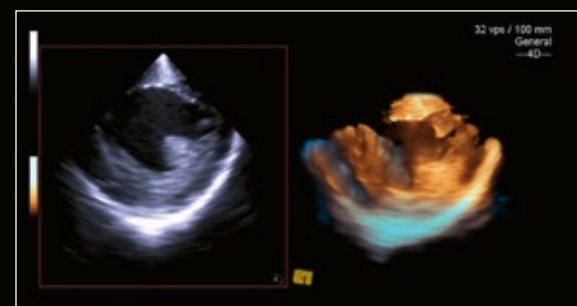
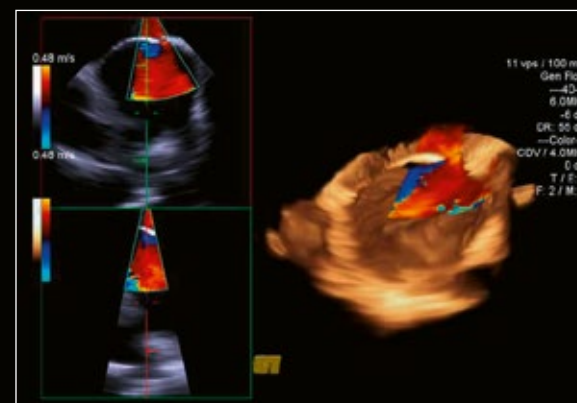
In the summer of 2000, Siemens made a public takeover bid for Acuson, and the deal was finalized in the same year. For Siemens, the acquisition was a key step toward becoming a one-stop supplier for its partners in the healthcare sector. Samuel H. Maslak, CEO and founder of Acuson, described the merger with Siemens as "an incredibly positive step for the entire industry," predicting "more research and development, better global distribution and services, more clinical applications, and better IT-based connectivity solutions," adding that "the potential for new, cost-effective contributions to patient care from ultrasound is now greatly expanded." From this point on, the two companies merged to develop products and solutions for ultrasound diagnosis.

Siemens Ultrasound is headquartered in Mountain View, California at this time.

After the merger with Siemens, the ACUSON Sequoia system was further refined and expanded with updates. As a result, Siemens Ultrasound was ranked first for the fifth time in a row in a 2004 report by Klein Biomedical Consultants (KBC), a highly regarded agency in the ultrasound market. At the time, the ACUSON Sequoia system had been the top-selling ultrasound system on the U.S. market for eight consecutive years, and it is currently the top-selling ultrasound system of all time.



The ACUSON AcuNav intracardiac ultrasound catheter is inserted into a patient's right ventricle to produce images from within the heart



Straight to the heart

The merger coincided roughly with the market launch of a unique, special transducer that was the culmination of eight years of research by Acuson in collaboration with the Mayo Clinic in Rochester, Minnesota. The ACUSON AcuNav™ miniaturized ultrasound catheter could be inserted into a patient's right ventricle via the jugular or femoral vein. The transducer, measuring about 3.3 millimeters in diameter, contained 64 piezo elements able to withstand even the rigors of electric shock treatment with a defibrillator. The ACUSON AcuNav ultrasound catheter was able to deliver high-resolution images of the cardiac muscle and monitor cardiac blood flow using Doppler imaging. The output images revealed structures from within the heart that no other contemporary imaging technique could capture, making the ACUSON AcuNav ultrasound

catheter a highly valuable aid in the diagnosis and treatment of heart disease and arrhythmia.

The first product that was launched after the merger of Siemens and Acuson was the successor to the SONOLINE Elegra system. The SONOLINE Antares™ ultrasound system was the smallest and lightest premium system of its time, with a footprint of 62 by 99 centimeters, weighing just about 160 kilos. Containing over 90 patented technologies, it featured an entirely novel user interface: the Siemens syngo® image processing and management interface, connecting the SONOLINE Antares system to other imaging systems in a clinical image network. The syngo software enabled faster workflow, could be expanded to include new functions, and was compatible with contemporary clinical software applications.

Accessing two new dimensions

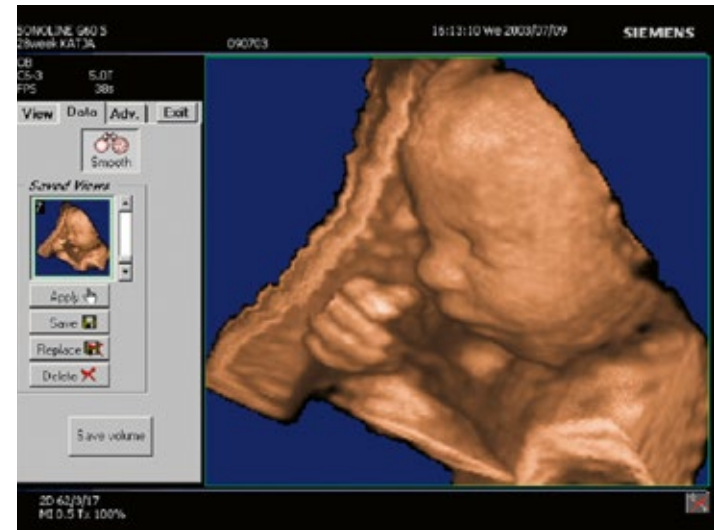
Whereas software programs in older equipment were designed to control just a few of the device's technical functions, by the early 2000s they were a core component of any ultrasound system. Software was used to guide the operator in matters such as proper positioning of the transducer, optimize the image display at the touch of a button, and even to enable entirely new applications. For example, in 2002 Siemens became the first manufacturer to offer three-dimensional imaging as an upgrade or add-on for a majority of its ultrasound systems, from entry-level to high-end models. The 3D Express™ ultra-fast 3D rendering technology software was able to process the signals from any suitable Siemens transducer with no need for hardware upgrades. 3D imaging was a great benefit to both ultrasound users and patients: In the early stages of pregnancy,



The ACUSON AcuNav catheter features a miniature transducer with a 3 mm diameter



The SONOLINE Antares was the smallest and lightest premium ultrasound system of its time



4D visualization of a fetus from 2004

for example, sonographers could observe body structures that were very difficult or even impossible to detect using two-dimensional imaging. The possibility of early intervention in the event of anomalies made 3D imaging an important clinical tool. Furthermore, from early on expectant mothers could enjoy vivid images of their babies that required no expert knowledge to interpret.

If movement is added to three-dimensional images, the result is known as 4D imaging. The fourth dimension—time—significantly enhances an examination's diagnostic value, particularly in cardiology applications such as monitoring heart function in real time, with virtually no delay. In 2004, Siemens combined the 3-Scape imaging software with real-time imaging for its *fourSight*™ 4D transducer technology. *fourSight* 4D technology comprised a range of 3D, 4D, and Doppler imaging functions optimized for numerous different applications. Where necessary, the software was able to convert previously captured 2D images to 4D.

Dizzy heights for portable ultrasound

A team of medical practitioners from Germany's Giessen University Hospital chose a rather unusual location to research potential treatments for lung diseases: Mount Everest, the world's highest mountain. The team set off on April 7, 2003, aiming to reach the 8848-meter summit at the latest by May 29 of the same year—exactly 50 years after the first ascent by Sir Edmund Hillary and Tensing Norgay. In their bags were two ACUSON Cypress™ echo-cardiography systems. The goal was to use the compact, sturdy devices to help find targeted treatments for patients suffering from pulmonary hypertension—a disease affecting 10–15 percent of the world's population, mostly people with chronic

heart and lung problems. The high mountain terrain was an ideal setting in which to simulate the symptoms of pulmonary hypertension. The test subjects accompanying the expedition were mountaineers and competitive athletes in prime physical condition, whose pulmonary vessels would be quick to regenerate after the experiment.

The bulk of the tests were carried out at the Mount Everest base camp, at an altitude of 5364 meters. Part of the expedition team then returned to Giessen to evaluate the wealth of medical data and findings, while the remainder of the group set off for the summit, arriving on May 26, three days ahead of schedule. Back in Giessen, the researchers concluded that “even temperature swings from +40° C during the day to below -20° C at night caused no lasting harm either to the highly motivated test subjects and medical professionals, or to the equipment itself.” The ACUSON Cypress system proved to withstand severe strain and still deliver outstanding images, just as reliably as its larger and more powerful cousins.

Ten times smaller than a human hair

From the mid-2000s, contrast agents began to play an increasingly important role in ultrasound. The first generation of contrast agents would disintegrate upon coming into contact with ultrasound waves, limiting their usefulness for imaging to a very short period of time. Second-generation contrast agents, known as microbubbles, remain in the patient's bloodstream for up to 15 minutes. They are made up of gas bubbles about 10 times smaller than the diameter of a human hair. Once they have been injected into the body via a vein, the microbubbles accumulate in greater concentrations in suspicious areas, amplifying the

ultrasound echo. Tumors marked with contrast agents can be more clearly distinguished from the surrounding tissue. Metastases in the liver, for example, are shown in much darker shades than healthy liver tissue. In 2005, Siemens launched a new technology optimized for these new contrast agents called *Cadence*™ contrast pulse sequencing (CPS) technology, which emits specific pulse sequences that cause the gas bubbles to vibrate. The technology's signal processing functionality



Cadence harmonic imaging enables the visualization of liver lesion

is designed to clearly distinguish the echo of the microbubbles from that of the surrounding tissue and display it in high contrast. The procedure is so accurate that physicians can even watch the contrast agent flowing into the tissue on the monitor. Within minutes of the examination, the bubbles are expelled from the patient's body via the lungs.

The ACUSON Cypress at the base camp of Mount Everest in 2003





The ACUSON P10 handheld ultrasound system was the smallest ultrasound system in 2007

Handheld ultrasound

By the mid-2000s, ultrasound systems were so advanced that they could provide valuable diagnostic information in almost every medical discipline, with one notable exception: They were too heavy and cumbersome to be transported to an accident site in an ambulance or rescue helicopter. However, in first-aid situations the first minutes of treatment are often crucial. To assist the diagnostic efforts of emergency personnel in intensive care units or medevac vehicles, Siemens developed an ultrasound system small and light enough to be carried in a doctor's coat pocket. The ACUSON P10 system—at the time of its launch in 2007 the smallest ultrasound system in the world—weighed just 700 grams, allowing it to be held in one hand and operated with the user's thumb.

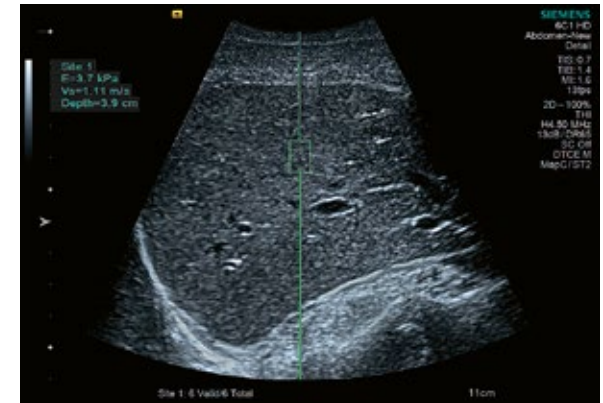
This miniature ultrasound system had a start-up time of just a few seconds. During triage—the process of determining which patient is most urgently in need of care, for example, after an accident with multiple victims—the ACUSON P10 system could deliver high-resolution imaging for up to 1 hour before the battery had to be recharged. Special emergency

programs enabled the device to monitor heart activity or detect accumulation of fluids in the body. This meant that emergency personnel could diagnose injuries before the patient had even left the accident site and request the most appropriate treatment at the hospital.

Hippocrates and the stiffness of tissue

Diseased tissue is often harder and less elastic than healthy tissue, a principle that Hippocrates and his students relied on in their diagnoses 2400 years ago. The more accurately the elasticity of tissue can be determined, the sooner diseases can be diagnosed. The physicians of antiquity would examine their patients' bodies by touch, using their fingers or the palms of their hands, a method known as palpation that is still used today. Mostly, however, the determination of tissue characteristics is made via a classical biopsy, in which pathologists examine a tissue sample under a microscope or subject it to chemical analysis. By the mid-2000s, medical equipment was powerful enough to determine tissue characteristics with the help of ultrasound and magnetic resonance imaging (MRI). The technological counterpart of palpation is known as elastography imaging.

Starting in 2007, Siemens launched a number of technologies designed to help physicians evaluate tissue stiffness and draw conclusions based on the results. The eSie Touch™ elasticity imaging application was optimized for manual surface elastography, and could be used in case of suspected lesions. The software allowed sonographers to instantly generate an elastogram providing an overview of the tissue structures in the area of interest. Manual elastography uses gentle pressure applied to the patient's body with an ultrasound transducer. In many cases, the resistance created by the patient's heartbeat or

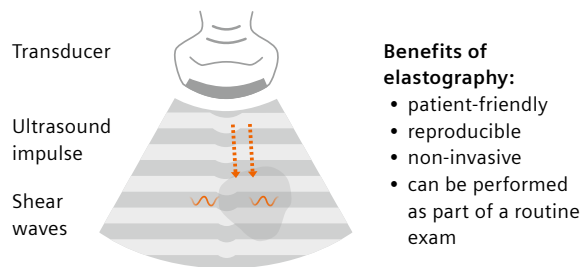


Elastography examination of the liver

breathing is sufficient. No additional equipment is required for manual elastography other than state-of-the-art transducers and ultrasound systems.

Siemens was first to use acoustic radiation force impulse (ARFI) technology in ultrasound elastography research as part of a commercial ultrasound imaging system, the ACUSON S2000™ ultrasound system. ARFI imaging on the ACUSON S2000 system, the first in the ACUSON S Family™ of ultrasound systems, was marketed under the brand name Virtual Touch™ technologies. Virtual Touch™ imaging (VTi) and Virtual Touch™ quantification (VTq) expanded the scope of conventional manual elastography, precisely measuring tissue stiffness by means of a targeted, computer-guided electronic push pulse. VTq can be used to reach deeper body areas such as the liver, which cannot be scanned using manual elastography. What is more, electronic pulses made the stiffness measurements more reproducible and operator-independent, enhancing the procedure's diagnostic value.

Shear Wave Elastography



3D images like none seen before

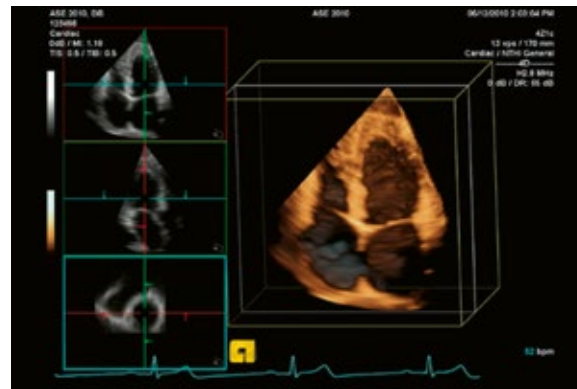
The ACUSON SC2000™ ultrasound system, launched in 2009, was the world's first echocardiography system to deliver 3D images of an entire beating heart in real time. To achieve this view previously, images from up to eight heart cycles had to be stitched together. In order to cope with the vast amounts of data required by this process, the ACUSON SC2000 system was equipped with a CPU that was about 16 times faster than those of conventional ultrasound systems.



The ACUSON SC2000 echocardiography system

IN Focus coherent technology, a refinement of the ACUSON Sequoia system's coherent imaging technology, delivered optimized detail and contrast resolution across the entire field of view rather than just in a particular area. The ACUSON SC2000 system is equipped with numerous workflow enhancement features such as automated analysis tools and navigation aids to improve workflow and facilitate interventional procedures.

Two years later, Siemens unveiled an ultrasound system designed specifically for the diagnosis of breast disease: The ACUSON S2000™ Automated Breast Volume Scanner (ABVS) automatically delivered 3D scans like none seen before in the ultrasound industry. The system generated a coronal view of the breast—from the skin line to the breast wall—showing anatomy, symmetry, and deformations of the breast architecture and structure. If a lesion requiring further examination was found on the 3D scan, the operator could capture additional 2D images with a handheld transducer, using color Doppler and elastography imaging.



Imaging of the entire heart in one heart cycle and in real-time

A big part of the solution

In spite of the spectacular successes achieved in the previous decades, there was one development that was long held to be practically unachievable: An ultrasound system using wireless transducers. The sheer volume of data to be sent from the transducer to the image processing unit is staggering. However, Michael Cannon, founder of the Penrith Corporation, acquired by Siemens in 2012, overcame this challenge after working on the technology for about six years. When Siemens launched the world's first wireless ultrasound system, the ACUSON Freestyle™ ultrasound system, the compact housing and transducers included cutting-edge acoustic technologies, radio technology, system architecture, miniaturization, and image processing. These were combined and optimized to meet the particular requirements of a premium ultrasound system.

"We didn't start out just saying, let's build a wireless transducer," recalls Michael Cannon. "We said, let's solve a clinical problem, and the wireless transducer



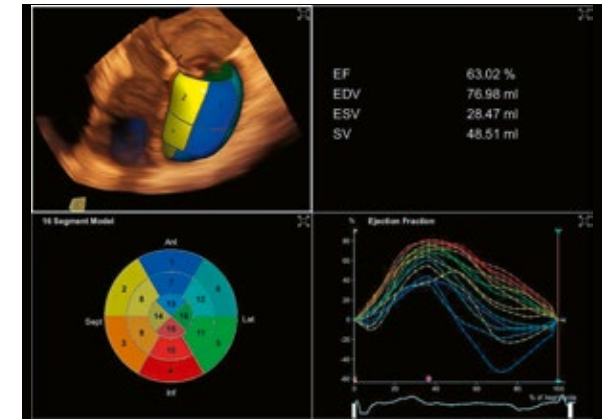
The ACUSON Freestyle is the first ultrasound system featuring wireless transducers



Breast views acquired using the ACUSON S2000 ABVS system

The ACUSON S2000 Automated Breast Volume Scanner acquires 3D volumes of the breast

The ACUSON SC2000 provides more than 200 automatic measurements. This improves diagnostic confidence and reproducibility.

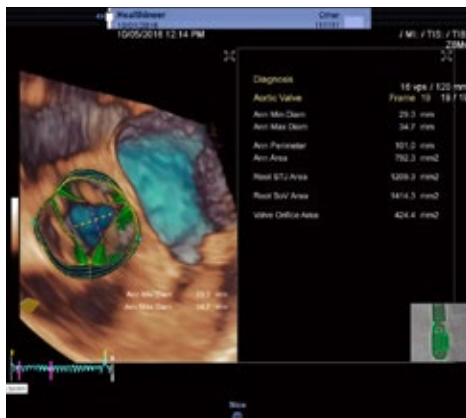


Ventricular analysis using the ACUSON SC2000 echocardiography system

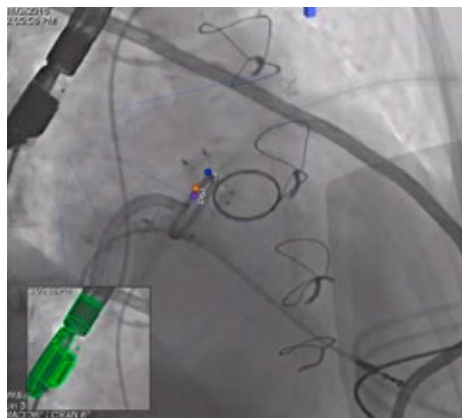
became a big part of the solution.” The clinical problem the team wanted to solve was the use of ultrasound in surgical and interventional medicine. Until then, transducer cables had often been something of a nuisance during procedures, hampering the efforts of surgeons and other medical personnel. More importantly, transducer cables are an infection risk. Wireless transducers avoided these problems as they could be easily wrapped in sterile protective covers and gave physicians complete freedom of movement. The ACUSON Freestyle system’s user interface could be operated using controls located on the transducer. Many other technologies used in the system were designed to optimize workflows and improve point-of-care efficiency.

Vision into the heart with TEE

To examine even the tiniest structures in the heart, such as blood clots, special transducers can be positioned just behind the patient’s heart via the



Guiding landmarks for fusion from True Volume TEE



Tee landmarks for target-oriented device navigation

A new era of ultrasound

Healthcare is changing, and so too are the requirements for ultrasound systems. To develop the latest generation, Siemens Healthineers worked with 365 users around the world. A total of 170 workshops were held with users in order to tailor the development of platforms to their needs. These platforms were launched in 2018 and 2019 as part of three systems aimed at different sets of requirements: ACUSON Juniper, ACUSON Redwood, and the new generation of the ultra premium system ACUSON Sequoia.

esophagus. This procedure is known as transesophageal echocardiography (TEE). In 2015 Siemens launched the ACUSON SC2000™ PRIME ultrasound system with the new True Volume TEE transducer able to simultaneously image the heart's shape, function, and blood flow in real time, even in patients with cardiac arrhythmia. The highly detailed images help physicians to make the right decision quickly in complex situations, such as heart valve surgery. In the upcoming years, the TEE volume imaging developed into a valuable tool for monitoring and navigating minimally invasive intercardiac interventions on the heart, in addition to diagnosing cardiac structures and functions. With the snygo TrueFusion feature, the ultrasound informations will be fused live with the fluoroscopy images to achieve even more safety when placing heart valve replacements or LAA closure devices. To prevent image distortions during the intervention, the transducer is shielded from electromagnetic interference and designed to minimize overheating.



Between breathing and whispering

ACUSON Juniper is the smallest, lightest, and quietest ultrasound system of its class. At just 28 decibels, the operating noise level lies between the volume of breathing (about 25 decibels) and that of whispering (about 30 decibels). Compared with similar systems, ACUSON Juniper is up to 27 percent lighter and up to 36 percent smaller. Thanks to its effortless transport, small footprint, and numerous potential applications, the system is suitable for use across all clinical departments—whether it's cardiology, urology, orthopedics, or the operating room.

With its Quickstart function, the ACUSON Juniper is ready for use in just five seconds. In its latest release, the battery-driven model can even be used immediately without any delay. The system is equipped with 19 transducers and can therefore be adapted quickly and easily to suit the patient and



Slight mitral valve insufficiency depicted using ACUSON Juniper's True Fidelity Color Doppler technology



In 2018, ACUSON Juniper was the first system of the new ultrasound generation from Siemens Healthineers

the type of examination. For example, advanced ultrasound technologies such as eSie Touch elasticity imaging allow tissue elasticity to be determined at the touch of a button. Other significant factors in ultrasound examinations include the time taken to complete the scan and the user-friendliness of the system. With scan protocols specifically tailored to the operator, ACUSON Juniper guides users through the scanning procedure step by step so that they always know which views are needed and what other measures are necessary in order to carry out a comprehensive examination. The various automation tools provided by ACUSON Juniper also reduce the user-dependent variance that can arise in any ultrasound examination—including variance due to the different physical characteristics of each patient. Accordingly, the results are more accurate, more consistent, and more reproducible for almost every patient and in almost every situation.

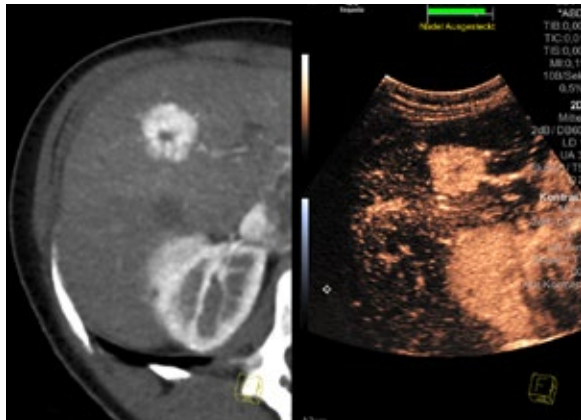
Profound insights

The first model of ACUSON Sequoia from 1996 served as the benchmark for the development of high-end ultrasound systems—and to some extent continues to do so today. Indeed, the engineers designing the original unit had the same objective as those working on the new generation of ACUSON Sequoia two decades later: to minimize variation between the results of ultrasound scans with the help of technological solutions. This is because, whereas imaging techniques such as computed tomography scan patients in a standardized manner, ultrasound examinations call for special capabilities on the part of the operator in order to produce diagnostically relevant images. Likewise, the individual physical characteristics of the patient can attenuate or affect the ultrasound signal. These "bioacoustic" characteristics of the

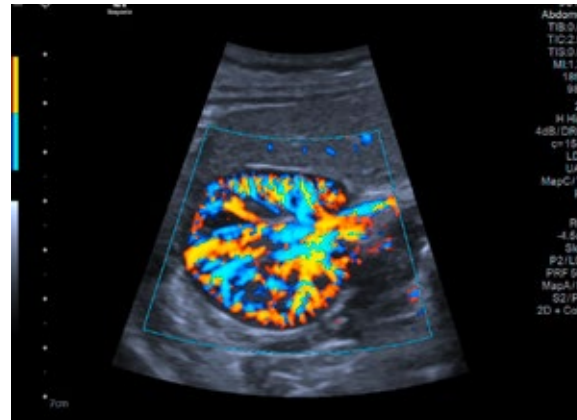
ACUSON Sequoia, the flagship ultrasound system from Siemens Healthineers, is suitable for patients of all sizes



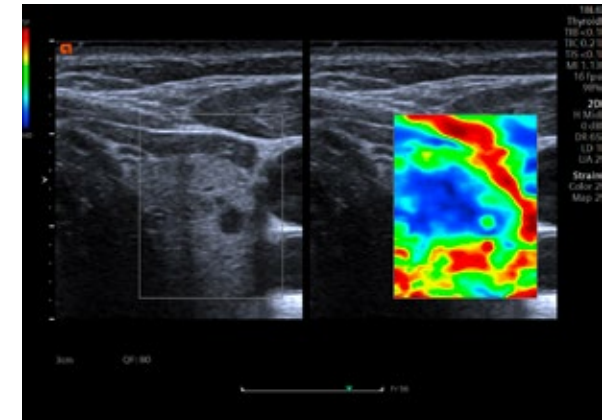




CT-ultrasound fusion imaging of the liver using a contrast agent



The volume of data recorded by ACUSON Sequoia each second corresponds to that of a 40-minute video streamed in 4K



Virtual Touch Strain Elastography provides a simple and qualitative representation of lesion stiffness, relative to the surrounding tissue.

patient—such as water content, muscle mass, or bone density—can vary widely depending on sex, age, size, and weight. Obese patients in particular have always been one of the major challenges in ultrasound diagnostics, because the deeper the sound waves need to penetrate, the weaker the echo and therefore the poorer the resolution of the image.

In the past, users could obtain diagnostically relevant images from deeper regions of the body in patients with a high body mass index (BMI) by adjusting the focus of the ultrasound beam, but they had to accept limitations in frame rate as a result. Every single component of the new ACUSON Sequoia—from the power supply to the transducer and even the graphics processor—is designed to compensate for possible attenuation of the ultrasound beam and to adapt to the patient's body in real time.

As a result of this BioAcoustic technology in ACUSON Sequoia, users no longer need to adjust the focus—the image is sharp across the entire field of view. The advantages of the BioAcoustic technology can be seen even more clearly on the OLED display of ACUSON Sequoia than on conventional LCDs. The abbreviation OLED stands for organic light-emitting diode, and each individual pixel of an OLED display is a light source in its own right. As all of the pixels operate completely independently of one another, this display technology delivers extremely sharp contrast and colors—and pixels displaying black can be switched off altogether. Among other benefits, this creates a much clearer distinction between black and the shades of gray that represent tissue. On LCD monitors, black always looks slightly gray because of the way in which screens are backlit.

ACUSON Sequoia uses machine learning and proprietary software algorithms to standardize workflows and clinical outcomes. Another key component of the BioAcoustic technology are the extremely sensitive transducers for the acquisition of a broad spectrum of high-quality RF ultrasound data. In particular, the patented new Deep Abdominal Transducer (DAX) achieves penetration depths of up to 55 cm and is predestined for the acquisition of multiparametric data from clinical applications such as elastography, contrast enhanced ultrasound (CEUS) and fusion imaging, and the new UDF (Ultrasound Derived Fat Fraction) technology for determining the fat content of the liver. In the future, it will also be possible to expand ACUSON Sequoia seamlessly with new applications from Siemens Healthineers. Indeed, the system has a modular structure and—unlike traditional unibody ultrasound systems—can be kept constantly up to date, even in the face of rapid technical development.

Combined technologies

Launched in 2019, ACUSON Redwood is designed as a “shared services” system that meets the same stringent standards of functionality and image quality not only across various hospital departments but also directly at the patient’s bedside. Like ACUSON Sequoia, the lightweight and portable ACUSON Redwood also processes ultrasound signals using coherent image formation, taking account of frequency and phase position, in order to boost image quality relative to that of conventional ultrasound units. The system combines numerous technologies from ACUSON Juniper and ACUSON Sequoia, so that functions such as contrast-enhanced ultrasound and shear wave elastography are also available in this class of systems from Siemens Healthineers.

The technical highlights of ACUSON Redwood include the new single-crystal design of the transducers. This concept was already seen in ACUSON Sequoia and ACUSON Juniper and results in improvements in the sensitivity and bandwidth of the transducers. These benefits primarily affect examinations of the abdominal cavity and heart, where the increased penetration depth is an important prerequisite for obtaining high-quality diagnostic images. Digital assistants based on artificial intelligence (AI) handle everyday routine measurements on the user’s behalf. With its UltraArt™ universal image processing, for example, the system allows the user to select their imaging preferences at the touch of a button on the quad display. Like ACUSON Juniper and ACUSON Sequoia, ACUSON Redwood is based on the new platform architecture from Siemens Healthineers and can be expanded quickly and easily as new technologies become available.

From equipment supplier to strategic partner

From the first experiments with ultrasound for medical applications in 1935 to modern technologies such as ACUSON SC2000, the 3D TEE transducer or the ACUSON AcuNav Volume ICE Catheter, for example, the development of ultrasound diagnostics has been driven and shaped by numerous pioneers and engineers—including from Siemens and Acuson, which have operated under one roof since the turn of the millennium. These developers have always worked closely with users, and this long-standing collaboration has given rise to ACUSON Juniper, ACUSON Redwood, the new generation of ACUSON Sequoia, the current system families ACUSON SC and ACUSON NX, and the portable point-of-care systems ACUSON P500 and ACUSON Freestyle, as well as the corresponding infrastructure.

Today more than ever, this partnership lies at the heart of what we do. Together with our customers, we work to bring about further improvements in patient care and to overcome the challenges facing healthcare systems. As well as expanding our strengths in imaging and laboratory diagnostics, this also includes a growing portfolio of management, consulting, and IT services.



In June 2020 Siemens Healthineers announced that it was relocating the global headquarters of its Ultrasound business, Siemens Medical Solutions USA, Inc., from Mountain View, California, to Issaquah, Washington



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Artificial Intelligence (AI) Software application leveraging machine learning-based Artificial Intelligence to achieve the intended outcome.

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