Ultrasound moved from sonar and industrial research into medical imaging in the 1950s and 1960s. This breast scanner with enclosed water bath was used by Drs. K. Tanaka and T. Wagai in the mid-1960s. (Courtesy of the American Institute of Ultrasound in Medicine)
Today ultrasound is the prime tool for diagnostic imaging of fetal development, is used extensively in evaluation of the heart, and has widespread applications in the diagnosis of diseases of the newborn brain, in differential diagnosis and biopsy guidance of the female breast, in detection and diagnosis of gallstones and many other abdominal diseases, as well as in the evaluation of many more peripheral masses. Blood flow studies (especially in the arteries to the brain) and biopsy guidance almost anywhere in the body are now routine procedures.

Development of ultrasonic imaging was not simple, because virtually all aspects of image production, energy-tissue interaction, and anatomic-pathologic correlation had to be developed and defined. The medical establishment was not uniformly supportive; only the imagination, vision, and determination of individual users nurtured ultrasound in its earliest years.

The purpose of this chapter is to offer a broad overview of the development of this new technology with reference to the pioneers who contributed to its genesis, the growth of medical applications, and the involvement with manufacturers that has propelled the field to its present high level of utility.

**THE EARLY PERIOD: FIRST STEPS**

We have arbitrarily designated the early period as beginning with work leading up to the availability of ultrasound for testing and diagnosis and ending when the medical community acknowledged the importance of the new technology. During this period the concepts of the use of echolocation in naval warfare (sonar) and ultrasound for nondestructive testing were reformulated for human application, and the feasibility of obtaining meaningful images in human subjects was shown. The way was opened for commercial enterprises to produce clinically applicable instruments. Above all, a solid foundation for future widespread clinical applications was established. The endpoint of this early period is difficult to pinpoint but surely took place in the late 1960s, when many new investigators and users entered the field and initiated a huge wave of enthusiasm for the future of the infant technique.

Although ultrasound can be generated in many different ways, the typical method today is to use the piezoelectric effect of certain crystals. This effect was discovered by the French physicists Pierre and Jacques Curie in 1880.1
Typically, the piezoelectric crystals are used for both sending and receiving ultrasonic waves. The physical relationships among size, shape, and design of the piezoelectric crystal transducer permit the generation of directional ultrasound beams, which can be focused. This capability to determine direction as well as distance of an echo source from a pulse of sound by its time of flight was first used to locate submarines (naval sonar) and in nondestructive testing of materials. The earliest medical uses took place between the two world wars and consisted mainly of physical therapy and some attempts to treat malignant tumors.

The first actual diagnostic application of ultrasound that we have been able to document was by German physician Karl T. Dussik, who attempted to depict intracranial structures (Fig. 17.1). In 1942 he described the use of transmitted ultrasound to obtain a representation of the cerebral ventricles. He called his images hyperphonograms. According to neurologist W. Guettner in Germany, Dussik's images actually had more to do with attenuation of the sound by the bony skull. Nevertheless, the possibility of noninvasive (as we now call it) diagnosis of intracranial structures was intriguing, and other attempts to apply ultrasound to diagnosis soon followed. André Denier, a French physiotherapist, also proposed the use of ultrasound for diagnostic purposes but apparently did not accomplish this goal.

The earliest diagnostic reflected ultrasound technology used A-mode displays, with echoes shown on an oscilloscope as vertical deflections from the baseline and located along this baseline in direct correspondence to the depth of reflectors in the beam. The nature and importance of the individual signals were not understood, so that an attempt was made to save as many as possible for further study. However, in the early stages of this technology many of the signals were unreliable and unidentified in respect to what they actually represented. Many investigators, using electronic processing, discarded very small amplitude echoes, often on the presumption (sometimes correct) that they represented merely noise. The remaining signals were then amplified to the limit of the display. Fluid-filled spaces, which generated no echoes, became empty black areas, while tissues were filled with echoes, thus creating the cystic versus solid differentiation that dominated early ultrasonic diagnosis. The A-mode presentation was just a curve and so could not produce organ images. Users had to make often difficult anatomic correlations. A few early investigators (notably Wild) did anticipate the importance of the lower level echoes and attempted to incorporate them into tissue diagnosis.
Pioneering Efforts in America

Between 1947 and 1949 George Ludwig and F. W. Struthers performed innovative experiments at the Naval Medical Research Institute at Bethesda, Maryland (Fig. 17.2). Working with A-mode equipment, they investigated basic properties of ultrasonic waves in tissues and worked on foreign bodies and calculi, demonstrating that gallstones could indeed be seen by ultrasound. Later, Ludwig cooperated with Ivan Greenwood, an engineer at General Precision Laboratories, with R. H. Bolt of the Massachusetts Institute of Technology, and with H. T. Ballantine, a neurosurgeon (Fig. 17.3). Theodor Heufer from the Siemens company joined them in 1949. Ludwig eventually abandoned his ultrasound research and remained in internal medicine, becoming chairman of the department of medicine at the new Medical College of Ohio at Toledo in the early 1970s.

Meanwhile, John Julian Wild, a surgeon then in Minnesota, became interested in determining the thickness of intestinal walls in disease (Fig. 17.4). In 1949, using equipment derived from military radar devices, he showed that this was indeed possible and that tumors of the intestine could be identified. Normal bowel wall, inflamed thickened bowel wall, and cancer masses each gave a different A-mode pattern. With John M. Reid, then a student of engineering, he constructed several types of echoscopes—in effect, hand-held contact scanners (Fig. 17.5). They called their method echography, a most suitable term. Wild also anticipated future possibilities for the method and constructed vaginal and rectal scanners as well as a system for breast cancer screening. At that early stage of primitive electronic devices and self-constructed equipment, he realized the potential of ultrasound to detect and characterize soft tissue masses and anticipated the possibility of screening and of tissue characterization (diagno-
sis) by echo pattern—enduring evidence of his vision. In recognition of his contributions he was awarded the prestigious Japan Prize in 1991. This prize is awarded yearly to a living scientist who has contributed in a major way to the advancement of technology. Somewhat similar to the Nobel Prize, it includes a substantial financial award in addition to the honor.

As was often the case for early researchers, Wild was unable to work either at a military installation (apparently for security reasons related to radar equipment) or at the university, so much of this work was done in the basement of his home. In 1962 he received a research grant from the United States Public Health Service, but controversy arose about the administration of the grant. As a result, his laboratory was closed. Subsequent litigation resulted in a substantial financial award to Wild, but after that he worked outside formal institutions.

B-scan imaging began in the late 1940s and early 1950s, primarily as a result of the work of Wild and Reid in Minnesota and of Douglas Howry in Colorado. As mentioned earlier, Wild and Reid employed a B-mode contact scanner, while Howry championed a water bath system which allowed more comprehensive imaging, including compound scanning.

In A-mode displays the echoes were represented as spikes on a stationary baseline, “A” standing for amplitude. The spaces between the spikes represented distance (determined by measuring the time for the echo to return to the transmitter, which usually was the same piezoelectric crystal), while the height of the spikes represented the strength of the returning echo. The underlying concept of B-scanning is the conversion of the A-mode display of spikes on a fixed baseline to a series of dots on a floating baseline, the position of this line corresponding at any time to the position and direction of the ultrasonic beam scanning the object (the patient). The resulting series of lines of B-mode dots then are accumulated in a systematic sequential manner to form maps of tissue planes and organ outlines. The term B-mode refers to brightness: dots on the display representing echo sources in the body are of different intensities, the brightness of each dot being proportional to the strength of the returning echoes. The B-scan is an accumulation of all the B-mode lines of dots to make an anatomically corresponding image. This technique represented a huge leap forward in the effort to gain credibility for ultrasonography in the medical arena, since the images now looked somewhat like the real organs would appear in cross section.

Douglas Howry, a principal contributor to the development of clinical B-scanning, became interested in the diagnostic possibilities of ultrasound soon after graduating from the University of Colorado Medical School in Denver in 1947 (Fig. 17.6). He interrupted a formal residency in radiology to devote more time to his research, at first working in his own basement. He cooperated with Carl Spaulding of the California Institute of Technology and engineers N. Roderick Bliss and Gerald Pasakony.

In 1949, using components from radar equipment and electronic kits, they produced an echo ranging scanner oper-
eventually was instrumental in beginning the extensive collection of historical ultrasound materials now housed in the American Institute of Ultrasound in Medicine (AIUM) headquarters near Washington, D.C.

Although Howry's immersion system produced images of superb quality, the method proved impractical when seriously ill patients required study (patients were actually immersed in water in the tank, the liquid serving as a transmission path for the ultrasound from the transducer to the patient). Ultrasound at high frequencies does not travel well through air, therefore a liquid or jelly is used to couple the transducer to the surface of the patient. With engineers William Wright and Ed Meyer, Howry's team developed an articulated-arm compound B-scanner around 1961–1962. The mechanical articulated arm carried
the transducer at its end. A series of thin wires and pulleys served to indicate the position and angle of the hand-held transducer as it was moved over the skin surface of the body to form anatomically correct cross sections or scans. This instrument was the dominant design of many commercial machines for the next twenty years. Several other equipment manufacturers and individuals developed their own versions of the articulated-arm scanner.

Though the contact scanner revolutionized abdominal imaging and provided a strong impetus to clinical acceptability, it had several important drawbacks. While the original display oscilloscopes provided variable brightness of the echo-representing dots, these dots faded quickly. The scopes did not have the ability to accumulate the dot image. Although photographic film in the camera recording the image on the scope by the open shutter method resulted in a picture of all the dots (a complete image), the operator was unable to see this image as the patient was being scanned. This resulted in occasional gaps in scans and excessive overscans of other areas. Within a few years storage oscilloscopes became available, permitting the operator to see the image as it was building during the scanning process. Unfortunately, these scopes operated in the bistable mode: each dot was either on or off, with no representation of relative brightness (i.e., no gray scale). The solution developed by the early pioneers was hinged on sensitivity or gain control. Low gain settings were used, so that only the strongest echoes were available for the signal processing then in use. As a result, these early images were to a great extent composed of organ outlines representing organ capsules without much internal detail.

The contact scanner was clumsy to use, especially when it was necessary to alter the position or angle of the scanning plane. The time required to obtain a cross-sectional image varied from a few seconds for a single pass of the transducer to up to several minutes for a full-field compound scanned study. An artistic sense was required to fill in or appropriately "touch up" areas judged under-represented in the evolving image. The most experienced virtuosos created the most meaningful studies, while beginners might leave gaps in the data or "overpaint," thus destroying information. The long scanning times made location of relatively small structures, such as the common bile duct, tedious.

Pioneering Efforts in Europe

Although our focus in this chapter is on North America, we must stress that the development of this field has been successfully carried out in other parts of the world by imaginative individuals and that these efforts remain truly international. In 1953 Lars Leksell at the University of Lund, Sweden, diagnosed a midline shift in the brain in a child with an intracranial hematoma using A-mode sonography. In 1957 Marinus de Vlieger from Rotterdam, after visiting Leksell and Jeppson, first used flaw detection equipment, and then developed his own B-mode equipment to study the brain through both the intact and the surgically opened skull. The notion of noninvasively studying the brain was attractive, and much effort was spent in this endeavor, largely unsuccessful because of the hindering effect of the overlying skull. This preoccupation with intracranial structures caused many researchers to underestimate grossly the potential of ultrasound diagnosis in other parts of the body. The bony skull presented then (and to this day presents) an impediment to successful imaging of the brain. Even today, we use ultrasonography of the brain in fetuses and newborns, where the skull is thin, or during surgery through surgically created openings. Limited visualization of the vessels supplying the brain is now possible through the skull.

A special case was the use of A-mode measurement of the position of midline structures and their displacements (thereby suggesting intracranial mass-

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examinations of the heart. To achieve a clinically useful level of performance, it was necessary to modify the flaw detectors, to create a 35-millimeter film strip record for M-mode registration with a simultaneous electrocardiogram display, and to analyze the strange tracings. To find out exactly what each tracing represented and meant, phonocardiographic data, measurements of the various M-mode features, and pathologic findings had to be meticulously compared. Their brilliant work clearly indicated the vast potential of ultrasonic diagnosis in the heart.

The "M" in M-mode stands for motion. In the M-mode scanning, process, the ultrasound beam is stationary, but the echo dots are swept across the oscilloscope screen in proportion to time. Then, as the echo sources move toward or away from the transducer, a curve is generated representing this motion. An industrial collaboration with Siemens's medical branch in Erlangen, Germany, was pivotal to the success of this effort. In Düsseldorf, Sven Effert mastered the techniques from Lund and did extensive studies in mitral stenosis, validating the results of the originators of echocardiography.

Ian Donald, an obstetrician and gynecologist from Glasgow, was among the earliest to apply diagnostic ultrasound to these fields of expertise (Fig. 17.12). His interest was piqued by discussions with John Wild, W. V. Mayneord, and Dr. J. C. Turner at the Royal Cancer Hospital in the early 1950s. Each of these men was using ultrasound flaw detectors to diagnose brain tumors. With the assistance of Douglas Gordon, an early researcher in echoencephalography, Donald was able to obtain an A-mode Kelvin Hughes Company flaw detector. In 1956 he used it to identify ovarian mass-
ing two-dimensional bistable chest images of the fetus (Fig. 17.13). 20

**Pioneering Efforts in Asia**

Considerable pioneer activity was taking place at several Japanese institutions. In 1949 Nihon Muscn (Japan Radio) Company (now Aloka Co.) physicist Rokura Uchida built Japan’s first model ultrasound device for A-mode presentation. Kenji Tanaka at Juntendo University School of Medicine and Toshio Wagai, using a device designed by Yoshimizu Kituchi, reported detection of intracerebral hematomas and brain tumors with A-mode. 21 Wagai, in 1951, began looking for gallstones and masses in various parts of the body; S. Oka at Osaka University studied the brain, breast, abdomen, and uterus.

Pioneering Doppler research was carried out by Shigeo Satomura and Yasuharu Naito at Osaka University in the 1950s. Satomura first studied small vibrations of solid bodies and, at the suggestion of physician Kinjiro Okabe, analyzed motion in living bodies. 32 In 1955 they also studied the motion of the human heart using Doppler effect ultrasound (Fig. 17.14). 33,34,35,36 Ziro

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*Fig. 17.12 Portrait of Ian Donald, ca. 1975, performing a scan with a contact compound scanner of his design. (Courtesy of the American Institute of Ultrasound in Medicine)*

*Fig. 17.13 The automatic mechanical sector scanner, the world's first, designed and developed by Donald and Brown in 1960. The transducer sectored automatically as the transducer carriage moved across the pregnant abdomen. It was hoped that by mechanically maintaining a constant scanning pattern, the variability of results obtained with the manual contact scanner could be overcome. Used clinically by Donald for four years, the scans produced ultimately were not deemed significantly superior to those produced by the manually operated systems. Nevertheless, aspects of this system served as prototypes for the commercially successful Disonograph, also designed by Donald and Brown. (Courtesy of the American Institute of Ultrasound in Medicine)*
Kaneko and associates at Osaka University studied blood flow, also using Doppler effect ultrasound.\(^{27}\)

In China, Hsu Chih-Chang, reading of the early work of Edler and Hertz in 1955, developed his own A-mode and M-mode equipment. He carried out extensive clinical studies on a variety of cardiac abnormalities.\(^{28,30}\)

These groups worked independently of each other, as there were no national or international organizations dedicated to ultrasonic diagnosis. Although there were a few periodicals related to sound and ultrasound, many of the original reports of these pioneers appeared in obscure publications, sometimes in journals not even obviously related to the subject at hand. Nor was the research generally appreciated and supported, as is so often true of innovative work. The first major conferences permitting an interchange of knowledge in this field were held at the University of Illinois in 1952, 1955, and 1962, sponsored by William Fry, a pioneer in the therapeutic uses of ultrasound.

THE MIDDLE PERIOD:
A WIDE VARIETY OF APPLICATIONS

The middle period can be viewed as spanning two decades from the mid-1960s to the mid-1980s. It represents an era of explosive activity driven by a large wave of enthusiasts attracted both by the novelty of the method and the opportunity to enter a field of great potential. The era is marked by a rapid increase in the number and quality of available instruments and by the entry of industry giants capable of funding major developmental efforts. Centers of clinical and research activity emerged, with systematic investigations involving larger numbers of patients. Teaching evolved, publication of scientific papers and textbooks flourished, and multiple conferences and symposia became available to beginners and more advanced users of ultrasound in the various medical specialties.

The inventiveness of the pioneers during the early period, and their devotion to work under trying circumstances and often in unwelcome surroundings, had shown that it was indeed possible to obtain useful and important clinical diagnostic information with ultrasound. However, more widespread application and systematic clinical research with larger numbers of patients started only when commercially-produced diagnostic equipment could yield reproducible results comparable among different sites. At this point in ultrasound development, clinical researchers from many centers and various specialty groups in North America, Europe, Asia, and Australia directed their efforts to specific organs, areas of the body, or to techniques and systems.

Some of the following parts of this chapter read almost like a catalog, filled with names and items. We believe that this multiplicity of people and specialties involved in research and development of ultrasonography is the result of an inherent difference in the nature of ultrasonic examinations when compared to roentgenology, nuclear imaging, or magnetic resonance imaging. Namely, the transducer design and the physical nature of the waves directed development and application to specif-
ic, limited areas of the body or disease sites. Much of the development of other imaging methodologies has been related to the application of single large machines. For example: a roentgenogram of the abdomen includes the entire abdomen with many organs, whereas ultrasound examination is directed at and limited to a specific site. This "focused" vision of ultrasound has been applied several different ways by investigators coming from diverse medical and specialty viewpoints. Following are some of these many developments.

**Echoencephalography**

Until the advent of satisfactory X-ray CT, echoencephalography would remain a central and attractive research goal. Unfortunately, the overlying skull continued to pose difficulties. John J. Wild demonstrated brain tumor in the excised brain in 1951.\(^{40}\) Douglas Gordon and his research group at the Royal Cancer Hospital began echoencephalography research in England.\(^{41}\) In the 1960s Denis White and engineer David Makow examined the head submerged in a water-bath scanner (Fig. 17.15).\(^ {42}\) William McKinney

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**Fig. 17.15** David Makow's first prototype of a water-bath encephalographic scanner, ca.1963; Makow is the subject in the water tank. (Courtesy of the American Institute of Ultrasound in Medicine)
conducted central nervous system investigations at the Bowman Gray School of Medicine in Winston-Salem, North Carolina. Early work on echoencephalography was also carried out by Ross Brown, a Canadian then at the University of Oklahoma; H. R. Mueller in Switzerland; and Robert Ford and James Ambrose in England.

Another physician influenced by the Howry group was Donald King, a young radiologist at Columbia-Presbyterian Medical Center. He was later to combine his efforts with those of Juan Taveras and Ray Brinker in the purchase of ultrasound equipment for that institution. In the spring of 1962 he visited the diagnostic ultrasound group at the University of Colorado in Denver, his interest in the field having been stimulated by an article in a popular magazine that included an illustration of the organs in the body made by Howry and Holmes. At that time, Taveras, director of radiology at the Neurologic Institute at the Columbia-Presbyterian Medical Center, had an interest in echoencephalography and asked Ray Brinker, who had just completed his radiology residency, to “read up” on what was known about ultrasound. As a result, the three physicians combined efforts to obtain from Branson Instruments in Stamford, Connecticut, a commercial metal flaw detector which they used for evaluating the midline of the brain. Branson Instruments later supplied the ultrasound equipment sold by Smith Kline Instruments, which eventually bought Branson. Having started with the flaw detector, Brinker, King, and Taveras thereafter bought another echoencephalograhic instrument, made by Physionics, and in 1964 ordered the first contact ultrasound imager in an attempt to obtain cross-sectional images of the brain.

In 1965 Brinker followed Taveras to the Mallinckrodt Institute in St. Louis, where Brinker developed a water-immersion ultrasound scanner which was unsuccessful because of the difficulty in transmitting the ultrasound beam through the skull. Brinker is now chairman of the department of radiology at the Medical College of Ohio at Toledo. King, as director of ultrasound at Columbia-Presbyterian, has devoted most of his time to echocardiography.

In 1967 at Downstate Medical Center of the State University of New York, Dr. Lewis Grossman, a neuroradiologist and amateur physicist, directed an active laboratory at the Neurologic Institute with the assistance of Georgina Wodrow ska, one of the earliest ultrasound technologists. Grossman died in 1969 before his work could be brought to fruition. Michael Tenner, also a neuroradiologist and now chairman of radiology at New York Medical College, was asked to head the service. He helped to extend the use of echoencephalography beyond simple midline detection by identifying various components of intracranial anatomy.

In 1963 Marc Lapayowker, while at Temple University in Philadelphia, and John Kirkpatrick, at St. Christopher’s Hospital for Children there, used an Ekoline instrument to perform echoencephalography examinations, including examinations of children. With Dr. Renate Soulen, another radiologist at Temple, they attempted to duplicate the early work of cardiologist Harvey Feigenbaum in the ultrasound evaluation of pericardial effusion. Lapayowker would become the first chairman of the American College of Radiology Commission on Ultrasound.

Jan C. Somer of the Netherlands first developed and, in 1968, described a phased array transducer for studying the brain. However, he achieved only limited success because of the same problems others had encountered with the bony skull. The real-time display, however, did show the movement of intracranial blood vessels.

Echoencephalography itself has not become clinically useful except under circumstances where the skull is less of an obstacle: during surgery when the transducer can be applied directly to the brain, in the newborn through the fontanelles, and in the fetus with its thin cranium. Ultrasonography of other body parts bypassed echoencephalography in development during this period.
Obstetrical and Gynecological Developments

Once Ian Donald at the University of Glasgow, Bertil Sunden at the University of Lund, and engineer George Kossoff with William Garrett in Sydney, Australia, had demonstrated that reproducible visualization and measurement of fetal structures were possible, ultrasonic diagnosis in pregnancy was investigated in many centers (Figs. 17.16 and 17.17). Early pioneering contributions in Europe were made by Alfred Kratchowil in Vienna, Jens Bang in Copenhagen, and Stuart Campbell in England (Fig.

Fig. 17.17 Various scans produced by the UI's Mark II equipment, ca. late 1970s. The bottom left shows fetal anatomical detail of the ventricular system within the fetal head; the upper left shows the portal veins and aorta of the fetus as well as the umbilical vein. (Courtesy of the American Institute of Ultrasound in Medicine)
In North America, substantial contributions have been made by Lajos von Micsky and Louis Hellman in New York; H. J. Holmes, Horace Thompson, Kenneth Gottsfeld, and Michael Manco-Johnson in Denver; and, more recently, John Hobbins at Yale University in New Haven (now also at Denver), Roy A. Filly at San Francisco, and Ted Lyons in Canada (Fig. 17.19)."58,59,60,61

Standards for fetal development were established, and ultrasound diagnosis in pregnancy has become a standard and essential clinical and research tool.

**Abdominal Applications**

Another group that influenced a number of radiologists was led by J. Stauffer Lehman, former chairman of radiology at Hahnemann Medical School in Philadelphia (Fig. 17.20). He was a pioneer in clinical applications of ultrasound, specifically in the diagnosis of abdominal and pelvic abnormalities. The program developed as a result of a chance meeting in 1964 between Luther Brady, chairman of radiation therapy at Hahnemann, and Murray Smyth, also a radiologist, who was promoting the clinical uses of ultrasound equipment produced by Smith Kline Instruments. Smyth had approached several other medical schools and facilities in Philadelphia but found no interest. At that time, Smith Kline was producing the Ekoline A- and M-mode series for echoecephalography and echocardiography, and was considering adding B-mode two-dimensional ultrasound instruments to its product line.

At Brady's suggestion, Smith Kline Instruments provided the B-mode equipment and Lehman provided the staff to perform clinical tests. George Evans, a young radiologist who had trained at Hahnemann, was asked to organize the ultrasound laboratory and supervise clinical testing.62 It was his job to investigate the diagnostic applications of the chest ultrasound water-bath techniques and abdominal scanning. Evans has commented: "My personal aggressive enthusiasm toward ultrasound was tempered by the conservative yet perceptive approach of Dr. Lehman. His painstaking diligence
and his profound circumspection infected all who worked with him. His insistence for accuracy and reproducibility of results was ubiquitous. These characteristics were so ingrained in his approach to research that we did not make unfounded conclusions as regards to the diagnostic capabilities of ultrasound."

Marvin Ziskin, now professor of radiology at Temple University, became aware of ultrasound as a student in biomedical engineering at Drexel University in 1964, when Murray Smyth presented a seminar. In 1965 Ziskin became a research associate in the diagnostic ultrasound laboratory at Hahnemann under the direction of Lehman, who died in 1974, and Evans, now in private radiologic practice in Detroit. This group did some of the earliest large-scale clinical research with ultrasound imaging. In addition to investigating abdominal applications, they also carried out research in echoencephalography, echocardiography, and Doppler ultrasound. Evans's first paper was presented in December 1964 at the Greater Philadelphia Chapter of the Federation for Clinical Research. Ultrasound images from the Hahnemann laboratory were published in Life magazine in January and September 1965. This group presented the first exhibit of ultrasound at the annual meeting of the American Roentgen Ray Society (ARRS) in September 1965 and again at the Radiological Society of North America (RSNA) in November 1965.

Lehman, Evans, and Ziskin worked with nearly every ultrasound instrument manufacturer in the country at that time, and Lehman is said to have been instrumental in persuading the Picker X-ray equipment company to become involved in ultrasound. Picker later bought Physiocords and became the dominant force in two-dimensional ultrasound imaging in the 1960s and early 1970s. The company helped disseminate the use of ultrasound throughout the radiologic community.

In 1968 Barry Goldberg joined the diagnostic radiology staff at Hahnemann, where he worked closely with Lehman in expanding the clinical utility of ultrasound. Goldberg developed an interest in ultrasound during his radiology residency in Philadelphia at the Albert Einstein Medical Center in 1964. J. Gershon-Cohen, former chairman of radiology at the center and a pioneer in X-ray mammography, had just bought one of the first Ekoline A-mode ultrasound machines from Smith Kline Instruments. A few weeks after Goldberg started his residency he asked Gershon-Cohen about the machine in the hallway. Gershon-Cohen replied, "Well, that's something new—ultrasound. See what you can do with it."

Goldberg became enthusiastic about the technique as he and his colleagues taught themselves to use the equipment. Working with several members of the radiology staff, he published articles on a variety of subjects, including echoencephalography, echo-cardiography, and abdominal and pelvic diseases, as well as producing images of the fetus. With John Kirkpatrick, then chairman of radiology at St. Christopher's Hospital in Philadelphia, Goldberg was one of the first to investigate the use of ultrasound in pediatric radiology. Jan Pedersen and H. H. Holm from Denmark and, separately, Goldberg working with Howard Pollack, were the first to develop ultrasound-guided aspiration biopsy techniques. In 1965 Goldberg delivered one of the first ultrasound papers given by a radiologist at a meeting of the RSNA. He pioneered the development of formal education programs for physicians and technologists. He is now director of ultrasound at Thomas Jefferson University Hospital, where the ultrasound education programs have evolved into the largest such center in the world. Another similar vigorous program is directed by Fred Kremkau at Bowman Gray School of Medicine in Winston-Salem.

George Leopold began his radiology residency in 1965 at the Presbyterian Hospital in Pittsburgh. Elliott Lasser, then chairman of radiology, obtained a Smith Kline Instruments A-mode unit after the 1966 annual meeting of the RSNA and assigned several residents to...
evaluate its capabilities. Leopold was the only resident to maintain an interest, working first with echencephalography and then echocardiography. His introduction to B-mode imaging was through a Picker machine lent by the company to the hospital for evaluation. Shortly after a visit to Lehman’s laboratory, Leopold followed Lasser to the University of California at San Diego and dedicated himself to the clinical applications of diagnostic ultrasound. When Leopold arrived in San Diego in 1968 he called a local Picker salesman and told him he wanted to order an ultrasound machine. The salesman said, “Fine, Doctor, what is it? If we have such an instrument, we’d be happy to sell it to you.” This was to be the first such machine on the West Coast. Leopold’s early research was on abdominal ultrasound. He is now chairman of the department of radiology at the University of California, San Diego. Like Goldberg, Leopold stressed education, providing both formal and informal training programs. They, along with other early clinical pioneers, educated a whole generation of radiologists and technologists in the usefulness of diagnostic ultrasound.

Another center of clinical research and training was developed under Atis Freimanis, a radiologist at Ohio State University, who in the mid-1960s also visited Lehman’s laboratory to observe clinical work with the Smith Kline Instruments suspended water-bath scanner prototype. Originally interested in using the application to study the nervous system, Freimanis became impressed with the general diagnostic capabilities of ultrasound. At Ohio State he worked with Michael Asher, at that time a medical student interested in developing some collaborative research projects. They conducted early research on the imaging of enlarged retroperitoneal lymph nodes. Their experiences illustrate some of the unexpected turns in research. Their original plan was to look for retroperitoneal lymph node enlargements in patients with lymphoma (at that time, before X-ray CT, there was no satisfactory way to determine such enlargement). They planned to do so from the back of the patient, expecting to determine the total soft tissue thickness and thus identify node enlargements. As soon as they began, it was obvious that these structures could not be scanned satisfactorily from the back but, since they attempted to represent tissue echogenicity, they found that lymphoma nodes are relatively transonic and can be identified by scanning them directly (in this case, from the front). Since looking for enlarged nodes involved a systematic search, and they were familiar with X-ray tomography, they designed their own scanning system and techniques. The scanning equipment (an early Picker unit without a mechanical stage for positioning) had to be moved by hand for each scan plane. To be systematic, they identified the iliac crest and midline as base lines and painted scan level lines on the patient’s skin with washable dye. Today, of course, this is unnecessary, as the real-time scanning transducer can be moved freely over the abdomen or other area, permitting a rapid and complete search.

As this work was progressing, another medical student, Roy Filly, joined the group, devoting his efforts to some of their early ultrasound research on pancreatic abnormalities. Asher is now in private practice, and Filly is the director of ultrasound at the University of California, San Francisco. This is yet another example of how the early pioneers in clinical ultrasound provided the stimulus for the next generation of radiologists who, in subsequent decades, took ultrasound to its current high levels of use. Freimanis would become chairman of radiology at the Medical College of Ohio at Toledo and then at Ohio State, and for the last ten years a professor at Michigan State University. Still making contributions to ultrasound, he admires with awe the flood of scientific work generated by those in this field and by the detail (both as visible data and requisite clinical knowledge), for example, routinely seen in examining the fetus.

Fred Winsberg, radiologist and formerly director of ultrasound at Mount Sinai Hospital in New York, was first intro-
duced to ultrasound in 1967 while working at Lincoln Hospital in New York. As he stated in a personal communication, "Although I had been promised a renovated X-ray department, construction was delayed by the usual government red tape, and the only items I was able to purchase were those not requiring construction. Thus, I acquired a Hoffrel ultrasound machine designed for echocerebralography with M-mode capability." This machine was designed by Russ Upshoff, an engineer who had left Branson to form his own company. Dr. Winsberg soon became disenchanted with cerebral midlines, but fascinated by echocardiography. He presented his first work in differentiating the left from the right ventricle in 1968 at the annual meeting of the AIUM. In spring 1970 he traveled to Germany to see the first and only real-time ultrasound instrument at that time, a Vidoson made by the Siemens Corporation. He was the first to use this machine in North America, at McGill University in Montreal, where he performed ultrasound on a full-time basis. Dr. Winsberg worked with another radiologist at McGill, Catherine Cole-Bugelet. Using the Vidoson, which featured a rotating transducer placed at the focal point of a parabolic mirror producing real-time images, they were able to visualize the aorta and demonstrate pulsations, establishing the value of real-time ultrasound.

A number of others, both radiologists and nonradiologists, have made important contributions. Nonradiologists include Ross Brown, who was director of ultrasound in the department of radiology at the University of Oklahoma in the 1960s and early 1970s, and Kenneth Taylor from England, who has been the director of the division of ultrasound in the department of radiology at Yale since the early 1970s. In addition, in the early 1970s Roger Sanders, another English radiologist and a former director of ultrasound at Johns Hopkins University, made important contributions; and Donn Bascho, now medical director at Baptist Cancer Hospital in Gadsden, Alabama, was the first radiologist to use ultrasound as an aid in planning radiation treatment.

After the establishment of echocerebralography as a reliable diagnostic procedure for gallstones, several investigators, including Leopold, Filly, Goldberg, and Peter Cooperberg contributed to establishing the ultrasound findings and appearances of the bile ducts, intrahepatic vessels, and the anatomy of the liver and surroundings. Francis Weill at Besançon in France made contributions to examination of the abdominal viscera. Early work in correlating ultrasound images with anatomy was carried out by Fred Sample, formerly director of ultrasound at the University of California at Los Angeles, and Eli Kazam, director of ultrasound and CT at the Cornell Medical Center in New York. Sample, together with Dennis Sarti, published a large atlas of B-scan diagnostic ultrasound images which remained useful and popular for many years.

Hans Henrik Holm at the Gentofte Hospital in Copenhagen, beginning with the purchase of an A-mode unit, established an extensive research team investigating several aspects of abdominal scanning with special interest in renal cysts and other surgical lesions. Among other subjects, they developed and popularized techniques for ultrasound-guided puncture techniques and biopsies. They also quickly recognized the advantages of the two-dimensional images of B-scanners, designed their own articulated-arm B-scanner, a transurethral scanner, and used a linear array transducer for puncture guidance. Holm remains active today and is a vigorous proponent of ultrasound-guided interventional procedures.

Operative and Endoscanning Applications

Operative and endoscanning applications have held the interest of many researchers. Early on, John Wild developed both transrectal and vaginal probes. Endovaginal ultrasound was initially developed by Alfred Kratchowil of Austria and von Micsky of the United States in the 1970s. Von Micsky also developed a transvesical transducer.
Transesophageal ultrasound for the evaluation of the esophagus, stomach, and duodenum was developed in Japan and popularized by Morimichi Fukuda and others in Japan and Europe. Fukuda was the first to use ultrasound during laparoscopic procedures. In Denmark, Holm’s group developed a cystoscope-mounted transducer used to evaluate bladder tumors. Hiroki Watanabe in Japan developed a stationary transducer mounted on an “ultrasonic chair” on which the patient sat, the transducer extending into the rectum, for the diagnosis of prostatic cancer (Fig. 17.21). Martin Resnick at Bowman Gray School of Medicine in Winston-Salem developed a hand-held rectal ultrasound probe. This approach was popularized in Japan by Watanabe in the 1970s. In the 1980s dedicated transrectal probes became commercially available and, by the mid-1980s, prostatic ultrasound scanning had become an accepted diagnostic tool. Miniature probes for evaluation of the blood vessels were developed by Nicolaas Bom in the 1970s. Bernard Sigel, formerly chairman of surgery at the Medical College of Pennsylvania, performed pioneering work in intraoperative ultrasound as well as in the evaluation of vascular disease.

Breast Disease

Wild and Reid designed equipment specifically for breast scanning and did early work on the differentiation of malignant and benign disease by looking at the echo signal content of the returning echo complexes. This was an early and imaginative step into what would become the search for tissue characterization or tissue signatures (Fig. 17.22). Japanese researchers, including several already mentioned and, later, J. Takada, H. Ito, K. Takahashi, S. Hayashi, and T. Kobayashi showed substantial interest and progress in scanning of the breast and evaluating diagnostic criteria for various breast lesions (Fig. 17.23). In 1968 British physicist Peter N. T. Wells and collaborator K. T. Evans described a water-immersion breast scanner. Numerous subsequent attempts to develop useful immersion scanners were made, but so far none has proven clinically satisfactory. Additional contributors include Elizabeth Kelly-Fry at the Interscience Research Institute in Champaign, Illinois; and George Kossoff, David Robinson, and Jack Jellins at the Australian Ultrasonic Institute. Breast scanning is gaining popularity and is now used widely, not as a screening method, but for differentiation of benign cystic disease from solid lesions and, very effectively, for guidance for needle and other biopsies of such lesions.
Echocardiography

Soon after echocardiography was initiated in Lund by Edler and Hertz, John Reid, at this time a Ph.D. candidate in electrical engineering at the University of Pennsylvania, constructed an ultrasonic reflectoscope for echocardiography, and in 1961 teamed with Claude Joyner in producing the first clinical echocardiogram in the United States (Fig. 17.24). In Indianapolis in 1966 Harvey Feigenbaum investigated pericardial effusions and in 1968 began imaging the left ventricle. He developed methods to calculate left ventricular volume and function, and his textbooks on echocardiography have served as bibles in the field.

Raymond Gramiak, a radiologist at the University of Rochester, began work with ultrasound in 1966 when the radiology department unexpectedly discovered a budget surplus. Elliott Lipchik, a cardiovascular radiologist, suggested the purchase of an ultrasound machine because it appeared new and exciting. A Physionics unit was selected because it featured a storage oscilloscope for monitoring image buildup during M-mode sweeping or B-mode scanning. Gramiak showed interest in mastering the use of the new machine and soon obtained meaningful M-mode images of the mitral valve, virtually the only regularly recognized cardiac structure at that time. By varying beam directions away from the mitral landmark and into the area expected to contain the aortic valve, he was able to detect an echo-pattern complex that seemed to represent the aortic valve. By good fortune and, at about the same point in his development as an echocardiographer, Gramiak examined a patient in the cardiac catheterization laboratory during cardiac output studies with indocyanine green. Each intracardiac injection of the agent resulted in an intense contrast effect, which he recognized as an excellent method to correlate cardiac anatomy with the nonanatomic display of M-mode sonography. Contrast agents were vital in his identification of the aortic and pulmonic valves (Fig. 17.25). He was also the first to report direct imaging of blood flow, as well as a novel reconstruction method for two-dimensional motion imaging of the heart, which later incorporated computer assembly of images. He also conducted experimental myocardial infarct imaging in dogs and Doppler detection of left coronary artery blood flow—the highlight of his career. An exhibit on this subject received a Magna Cum Laude award at the RSNA annual...
meeting in 1972. In these and other efforts he was aided by Robert C. Waag, an engineer, and Jarle Holen, an engineer-radiologist.102

In 1972 Donald King of Columbia University developed stop-action imaging of the heart, stimulating interest in further advances in this field. In Rotterdam in 1971 Bum created his first prototype real-time linear array, which excited the medical community because of its vivid portrayal of cardiac motion, despite less than optimal resolution.103 In 1974 James Griffith, an engineer, and Walter Henry, a cardiologist at the National Institutes of Health, constructed the earliest successful mechanical sector scanner with a field of 30 or 45 degrees (Fig. 17.26).104 They obtained reasonably good resolution at a rate of thirty frames per second. Also in 1974 Frederick Thurstone and Olaf von Ramn at Duke University produced an early real-time phased-array system, which provided a 60 degree sector angle and incorporated a novel dynamic focus during the receiving phase for much improved resolution.105 David Sahn and Richard Meyers, pediatric cardiologists, contributed to the development of a wide variety of uses of ultrasound in congenital heart disease, as did adult cardiologists Richard Popp and Joseph Kissio.

Ophthalmology

The eye is a most suitable anatomical structure for ultrasonic examination. Although much of it can ordinarily be seen directly, the transparent structures often become obscured, and the retrobulbar structures are not directly visible at all. In 1956 G. Henry Muntt and William F. Hughes of Chicago demonstrated echoes from an intraocular neoplasm.106 Throughout the 1950s and 1960s Arvo Oksala in Finland and Gilbert Baum in New York worked on ultrasound of the eye.107 Baum did much of this original work with A-mode representation but, in collaboration with Ivan Greenwood, he constructed B-mode scanners for the eye (Fig. 17.27).110,111,112,113 Because of the small size of the eye and excellent sound transmission through it, higher frequencies (10-15 MHz) could be used to provide better resolution. Additional work on the eye was done by Edward Purrall and Adnan Sokollu at Case Western Reserve University in Cleveland, and by Nathaniel Bronson and Jackson Coleman in New York City (Fig. 17.28).114,115,116 Karl Ossoning started his work on ophthalmic ultrasound in Austria, but resettled to the United States and continues his work at the University of Iowa. Werner Buschmann, a German who worked with the Austrian firm Kretztechnik, designed a number of transducers including the first application of a linear (stepped) array.117
Doppler Ultrasound

Investigation of Doppler ultrasound continued in Japan after its initial development there, and in the United States was researched primarily at the University of Washington in Seattle under Robert Rushmer’s leadership. Dean Franklin developed the method for flow separation according to direction. Donald Baker provided the pulsed Doppler concept which sampled small volumes of flow and avoided the confusion of continuous wave which summated all flows in the beam (Fig. 17.29). Steve Johnson related cardiac M-mode to pulsed Doppler and lectured widely on the subject. Eugene Strandness, dean of American Doppler use, taught the utility of spectral analysis in diagnosis.\textsuperscript{118}

P. N. T. Wells from England also carried out pioneering research in Doppler and other aspects of ultrasound.\textsuperscript{119} French investigators T. Planiol, P. A. Perronneau, and L. Pourcelot made important contributions to the Doppler study of a variety of cardiovascular structures.\textsuperscript{120,121} An important impetus to the development of clinical application of Doppler came from Oslo and Jørle Holen, who used continuous wave ultrasound to determine the severity of mitral valve stenosis by calculating the gradient from the magnitude of the frequency shift. This seminal effort accelerated the use of Doppler in imaging the heart and peripheral vessels.

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Fig. 17.27 Early ultrasonic ophthalmoscopic equipment used by Baum, designed and built by Baum and Greenwood; this is Baum’s "second generation" B-mode scanner for the eye. Ultrasonic coupling was provided by water bath and goggle. This compound scanner detected tumors, cysts, and other lesions in the back of the eye. (Courtesy of the American Institute of Ultrasound in Medicine)

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Fig. 17.28 A scan obtained by Purnell with his General Precision instrument, ca. 1964, shows a small tumor near the optic nerve. (Courtesy of the American Institute of Ultrasound in Medicine)
TECHNICAL DEVELOPMENT OF SCANNING EQUIPMENT

At this point the development of equipment during this period should be reviewed. The first images were generally recorded with cameras photographing an oscilloscope screen. B-scan images, in particular, but also A-mode and M-mode representation, were often photographed using the “open shutter” method (the camera shutter was kept open during the scan to record the nonpersistence line of dots or A-mode pattern to produce a complete image). Development of the persistence (or storage) oscilloscope permitted the visualizing of more or less complete images of each section on the scope as they were produced by manual scanning. Once complete, the image could then be photographed. Persistence oscilloscopes did not have significant grayscale capabilities and, for a period of several years, many of the advances in ultrasound diagnosis were made without grayscale brightness representation.

Those researchers who felt that a grayscale was important used imaginative auxiliary approaches to obtain at least a degree of soft tissue representation. One approach was to routinely obtain several (two to four) images of each scan plane, each with a different gain setting on the system. One then had the ability to visually compare the different echo intensities. Another approach was to make several photographic exposures of the same slice on the same film frame, but with increasing gain setting on the system for each frame. Those echo representations which were present on all exposures (the strongest) appeared brightest on the final image, those that were present only on the last one or two exposures (the weakest) appeared less bright. Such mental gymnastics explain how the ultrasonologists of that time could come up with reasonably good diagnostic conclusions, when to the uninitiated observer the images appeared “like weather maps” as was often commented by outsiders.

In the early 1970s the Unirad and Rohr companies introduced a B-scan unit capable of direct grayscale representation. The analog and, a few years later, digital scan converter device enabled the recording of grayscale representation in each point of the scan as well as manipulation of the information to improve the diagnostic interpretability of the images.

In the 1960s several manufacturers in the United States, Japan, and Europe started producing diagnostic ultrasound
machines in quantity for clinical use. Besides those already mentioned here and elsewhere in this chapter, several manufacturers successfully produced and sold such machines. Physionics made an articulated-arm compound contact B-scanner which, with subsequent modifications, was the leading product both in design and number of units sold for a decade. Physionics was established in Colorado, but was soon bought and operated for many years by Picker. Unirad, a company originally making compound contact scanners with persistence oscilloscopes, became an important manufacturer with its gray-scale unit. Unirad was bought and incorporated first into the Technicare and then into the Johnson & Johnson companies.

In Europe, Kretztechnik of Austria manufactured B-scanners. The Siemens Corporation in Germany developed the earliest commercial real-time scanner, using rotating transducers in a self-contained water bath. The sound beams were reflected from a parabolic mirror in the bath, and passed into the patient through a flexible plastic front cover. In Japan, Aloka company began manufacturing a variety of ultrasound equipment.

The advent of gray-scale imaging created a veritable revolution in B-scan imaging. The intensity of returning echoes could now be displayed as a shade of gray so that the internal architecture and not just the outlines of organs could be studied. The scope of diagnostic possibilities increased dramatically, and the artistic skill required to form images was somewhat diminished. Highly meaningful images could now be reliably produced, and standardization from laboratory to laboratory began. Despite the quantum leap in image quality, however, studies remained time consuming and difficult. It must also be remembered that these early ultrasonographers were confronted with anatomic cross sections unique in radiology, and that few anatomic atlases were available to correlate the ultrasonic scans with body cross sections. In addition, no atlas showed the multiple nonstandard planes that B-scanners were capable of creating, so that considerable imagination and creativity were required to unscramble and understand these nonstandard planes and, especially, the distortions induced by disease.

Learning was primarily experiential, because skill in the field required eyehand coordination during scanning plus a vivid imagination to analyze the image as it built up on the screen. Very little help could be found in textbooks, journals, or through attendance at symposia.

Once the commercial potential of diagnostic ultrasound machines became obvious, numerous manufacturers entered the field in many countries. With effort these machines could produce excellent images. The clinicians who most needed and hoped for real-time two-dimensional imaging were echocardiographers, who were still working in a nonanatomic mode. M-mode recordings on several types of strip chart instruments were now capable of evaluating a variety of valvular conditions and of detecting pericardial effusion and atrial myxomas, but were relatively poor at assessing heart cavity size and especially shape. Blood flow could be surmised from valve motion, and leaflet flutter denoted impact by a regurgitant jet.

Pioneering ventures in two-dimensional imaging consisted of complex systems incorporating a water bath and mirrors, a line-by-line method featuring electrocardiographically-controlled ultrasonic emission, a commercial B-scanner with image buildup over many cardiac cycles to create static systolic and diastolic “frames” in correct anatomic relationship, as well as a reconstruction system using M-mode data to provide excellent temporal resolution. Anatomic resolution improved when a B-scanner and computer-controlled reconstruction were added. All were doomed to obsolescence because of their complexity or the delay in seeing completed studies. But they did stimulate the field by their sometimes dramatic presentations of cardiac anatomy and motion. The anticipation of real-time scanning was rapidly escalating.

The earliest systems quickly established the utility of real-time two-dimensional imaging by showing more
comprehensive valve studies, which revealed the motion of a segment of a valve and not just a point as in M-mode.125 (All B-scan images are two dimensional. By habit, echocardiographers use the term 2-D to represent real-time B-scans. The term is not used nearly as much in the rest of ultrasound practice.) Cross-sectional views of heart cavities and the coordinated motion of heart walls provided much-needed functional data. The development of the Duplex concept allowed intelligent selection of cavity diameters, dispelling the uncertainty and inconsistency of “blind” M-mode selection.126 Later, Duplexer also bolstered the application of Doppler ultrasound in the heart. The term Duplexer here denotes an ultrasound system which displays a B-scan image, but also permits determination of flow at selected points in the image; in other words, a combination of anatomical B-scanning and functional flow determination at identifiable anatomic locations.

In abdominal ultrasound real-time scanners provided many urgently needed capabilities. The real-time image instantaneously oriented the operator as to the area under study. Rapid angulation of the scanner quickly tracked along organs and located anatomic landmarks. Small targets such as bile ducts and gallstones could be routinely demonstrated. Beam sweeping was automated and standardized. High-quality studies were much easier to produce, and standardization of images was progressing toward reality. Real-time scanning was so effective that the contact scanner B-scan was rapidly displaced as the workhorse in busy clinical laboratories.

Because the hand-held articulated-arm scanner required so much judgment by the operator to produce a satisfactory image, attempts were made to develop automated systems. Early in the course of events, Ian Donald and the Howry and Holmes group in Denver had separately developed automated articulated arm-like scanners which imitated the rocking and sweeping motion of the transducer used by the manual operators.

This approach was not picked up by commercial developers except for some minor features. The Australian research group developed an automated system (the Octoson) consisting of eight large transducers mounted in a water bath on which the patient lay. The device automatically produced scans in preset positions and, because of the multitude of transducers, eliminated many of the “blind spots” that troubled scans done from a single source. The device worked well and was produced and sold commercially. It did not penetrate the markets in significant quantity, as the real-time hand-held linear- and phased-array systems became increasingly popular. The Johnson & Johnson Company and the Indianapolis group of researchers separately developed water-bath based automated breast scanners. Again, these did not gain significant application.

Real-time scanning entered widespread clinical use with the commercial availability of such machines. ADR (Advanced Diagnostic Research) developed the first commercially successful linear array scanner. Other successful innovations included the mechanically-moving transducer devices (made by Advanced Technology Laboratories or ATL) and, more recently, phased-array devices. The ability to search for and select the right locations and scan planes with real-time ultrasound units enables the operator of the equipment to obtain high quality and diagnostically productive images reasonably easily. At the same time, all manufacturers have continued to make technical improvements in signal reception and handling components of the devices, so that image quality has improved further. Today, diagnostic ultrasound studies are quite competitive with X-ray and other diagnostic imaging methods for the appropriate indications.

The digital scan converter was introduced in the early 1970s, initially to replace the inherently unstable analog scan converter. The convenience of computer handling of data in digital form and the explosive growth of digital image processing techniques
Ultrasound is one of the newer modalities available to radiologists for diagnostic imaging. Although ultrasonic waves are a form of radiant energy, the interaction of the sound waves with body tissues differs considerably from the interaction of X-rays with tissues. Therefore, the image representation of these tissues is also quite different. As a result, ultrasonographic images reveal information on organ architecture not visible in conventional X-ray projections. Blood vessels are readily demonstrated, because blood is usually represented as an empty, echo-free space, while solid tissues have reflectivity that shows parenchyma (functional elements) as textures or shades of gray.

In medical diagnostic work, X rays are used in the transmitted mode, and images result from attenuation of the beam, producing a shadow picture (conventional roentgenograms) or a computer-reconstructed image (CT). This attenuation is primarily a function of electron density of the body part. Today, almost all ultrasound imaging relies on reflection of the sound waves from interfaces within tissues of different acoustic impedances. The ultrasonogram (often also quite appropriately called the echogram) is a map of tissue or cellular interfaces reflecting the sound waves (returning echoes). Special techniques (e.g., Doppler principle ultrasound flow studies) permit the detection and display of moving interfaces, such as flowing blood.

have accelerated ultrasonic instrumentation development.

Smith Kline Instruments and Parker Laboratories in the 1960s produced early continuous-wave Doppler units for detection of fetal heart motion as well as for use in peripheral vascular disease. Many of the Doppler concepts put forward by Seattle researchers were commercially implemented by ATL and more recently by the Quantum company.
Real-time 2-D Doppler flow imaging (also known as color Doppler, since flow direction is color coded) was developed at Aloka Company Ltd. of Japan in 1982 and tested clinically by Ryozo Omoto, who published the *Color Atlas of Real Time 2-D Echocardiography* in 1983. This system represents the ultimate concept in Doppler ultrasound because it shows 2-D patterns of flow and includes direction and some modest capability to assess flow velocity in the 2-D format. The flow patterns are superimposed on a conventional B-mode image, and the system permits a Doppler M-mode as well as conventional spectral Doppler in pulsed and continuous modes. Color Doppler has had a major influence on echocardiography and peripheral arterial (carotid especially) and venous examination. The first commercially produced non-cardiac oriented color Doppler equipment was made by the Quantum Company (now Siemens) in the mid-1980s. Arterial abnormalities and tumor vascularity have been studied in the abdomen, pelvis, and other sites. The ultimate role of these color flow systems may well surpass current high expectations.

**SCIENTIFIC AND PROFESSIONAL ORGANIZATIONS**

During the early period researchers worked for the most part in isolation. There was no periodical literature; there were no conferences or societies dedicated to medical diagnostic ultrasound. The earliest use of ultrasound in medicine was in physical therapy, not in diagnosis. Therefore quite a few of the early publications are in literature pertaining to physical therapy. Although ultrasound is still used in physical therapy, diagnostic applications have become overwhelmingly important. Thus the AIUM, which had been established as a society mainly by those using ultrasound therapeutically, by the mid-1960s had become primarily an organization first of researchers and more recently of practitioners in the diagnostic field. The AIUM is now a society of several thousand members. It arranges large annual conferences, coordinates teaching and learning activities from its own headquarters in Washington, D.C., and publishes monthly the *Journal of Ultrasound in Medicine*.

Worldwide, many international ultrasound societies and alliances cooperate in the World Federation for Ultrasound in Medicine and Biology (WFUMB), which also publishes its own journal, *Ultrasound in Medicine and Biology*, arranges worldwide meetings, and otherwise seeks to encourage international cooperation in the field of diagnostic and therapeutic ultrasound.

For many years there were no medical specialty-oriented organizations dedicated specifically to ultrasonography, except for one, Societas Internationale pro Diagnostica Ultrasonica in Ophthalmologia (SIDUO). In the last twenty years such specialty organizations have been established; an example in the United States is the Society of Radiologists in Ultrasound. Other such societies are springing up; the International Society of Ultrasound in Obstetrics and Gynecology has been in existence for several years. Such proliferation of organizations seems inescapable and is occurring in all fields of medicine.

**CONCLUSION: MORE RECENT PERIOD**

On reading through the listing of researchers, developers, and practitioners in this chapter and descriptions of their work, one wonders what is the stimulus for individuals to take on these challenges? It seems there are at least three types of people involved. Many of the earliest investigators were individuals who perceived a need either in their work or in their research. A powerful example is the strenuous (though often frustrated) effort devoted to ultrasound imaging of the brain. Before the advent of X-ray CT, there really was no satisfactory way to visualize the brain encapsulated in the skull. As soon as reflected ultrasound was shown to work (even if only as a flaw-detecting tool), physicians needing to see
inside the brain, the heart, and the
uterus grasped at this opportunity.
Hence the early involvement by
neurologists and neurosurgeons, cardio-
giists, obstetricians, nephrologists, and
ophthalmologists.

As soon as the technology became
available, those whose primary work
was to apply ultrasound clinically
entered the field vigorously. Today diagnos-
tic radiologists make up a very large
percentage of all ultrasound users.
Clinical applications, in turn, con-
tribute much to the improvement and
systematization of the process.
The third group consists of
chemists, physicists, engineers, and
industrial establishments who research
the applications and effects of the phe-
omenon. They make original physical
and chemical discoveries and continue
to improve the technological base on
which practitioners can build.

Medical ultrasound, solidly estab-
lished during the early period, under-
got a technological and clinical revolu-
tion with broad expansion of
instrumentation and clinical applica-
tions. Computers were applied and inte-
grated, real-time two-dimensional
scanners were introduced, gray scale
improved tissue representation, and
ultrasound contrast agents made their
appearance. Scanning artifacts were rec-
ognized, diagnostic criteria were estab-
lished, and many clinically useful
diagnoses were reliably made. In addi-
tion, training for technologists and
physicians became widely available. No
longer the "new kid on the block," ultra-
sound found respectability, acceptance,
and a well-deserved position of confi-
dence within the clinical community.

The most recent period begins in the
early to mid-1980s and blends into the
continuum of current events. Lacking
the advantages of near hindsight we are
more vulnerable to oversight and judg-
ment errors in highlighting selected
activities. However, certain advances and
accomplishments can be identified as
hallmarks of progress. In the obstetrical
field, for instance, ultrasonic studies
have become so all-encompassing that
many view them as the "first physical
examination" of the fetus.

Today the insertion of miniaturized
transducers into body cavities results in
major improvements in image quality
of target organs as image degradation
by overlying tissue is reduced. In this
manner, markedly improved images of
the prostate, female pelvic organs,
heart, vessels, and other nonvascular
lumens are being obtained.

Multiplanar and three-dimensional
ultrasonography is emerging as a likely
enhancement of diagnostic capabilities.
Doppler ultrasound, both pulsed and
color, has developed to a remarkable level
of sophistication and made many diag-
nostic inroads. Non-Doppler approaches
to flow currently under development may
improve blood flow measurements. In
addition, methods to monitor ultrasonic
needle guidance have improved.

Through the imaginative efforts of
many researchers, ultrasonic diagnosis
has become a widely used, effective,
and safe diagnostic tool benefiting
many patients. It is widely accepted as a
substantial element in the education of
radiologists and is a part of the exami-
nation of the American Board of
Radiology. New and promising possibil-
ities are being explored.
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Ultrasonography