Ultrasound in Urology

SECOND EDITION

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Roger C. Sanders

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SECOND EDITION

Vicki, Andy and Jeff
and
Angie and Nigel

Preface

With publication of the first edition of *Ultrasound in Urology*, the editors attempted to present an up-to-date, comprehensive text detailing the clinical application of ultrasound in urological practice. With the collaboration of a urologist and a radiologist, the book met the goals, emphasizing the proper utilization of this imaging technique to gain information related to specific clinical problems.

The editors realize that ultrasonography is a constantly changing discipline, and technological developments over the past 4 years have made portions of the first edition obsolete. The introduction and rapid acceptance and utilization of real-time imaging have greatly enhanced the diagnostic ability of this technique in the assessment of disorders of the genitourinary tract. In addition, there has been the continued development of biopsy techniques and percutaneous procedures that can be performed most successfully under ultrasonic guidance. New applications continue to arise, and it is expected that further improvements will continue in the future. The authors of the chapters have, therefore, attempted to present not only the most modern and up-to-date information but have also emphasized new developments and procedures that will be available in the future.

We wish to express our deep appreciation to the contributing authors who have greatly facilitated the development of this book. Most were cooperative in adhering to the guidelines and responding to our editorial comments and changes. We would also like to thank our secretaries, Barbara Roseman, Pamela Oliveri, and Joan Batt, who have assisted in correspondence and final manuscript preparation. Finally, we would like to thank Mr. James L. Sangston of Williams & Wilkins for his encouragement and cooperation.

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Contents

CHAPTER 1

History of Ultrasound

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Ultrasound is a branch of acoustics which deals with the study and use of sound waves of frequencies above those within hearing range of the average person (frequencies above 20,000 cycles/second or 20 kHz). Many examples of the use of ultrasound are found in nature. Some animals—moths, porpoises, birds, dogs, and especially bats—use it for locating and identifying food, for navigational purposes, and for detecting danger. Lazzaro Spallanzini in 1794 demonstrated that insectivorous bats depend on hearing rather than vision to locate obstacles and prey. An excellent review of ultrasonics is presented by Ensminger and White (1) in which all of the various applications of ultrasound are described. Also included are the various contributions made by physicists and mathematicians beginning in the 17th and 18th centuries.

One of the most notable contributions made was by Jacques and Pierre Curie (2). Their studies of crystals, under the direction of and in cooperation with Charles Freidel, were primarily concerned with pyroelectricity, a phenomenon that had been known for some time and consisted of the appearance of electrical charges on certain crystals as they were heated. Research in symmetry of crystals led to the discovery of piezoelectricity, a property of nonconducting crystals that have no center of symmetry. Their first observations, published in 1880, discussed the physical characteristics of many different crystals, and in 1881, using quartz and tourmaline, they published information demonstrating that when an alternating electrical field was applied to their crystals, the piezoelectric plates of the two substances underwent either expansion or contraction and produced sound waves of very high frequency.

The first practical application of their phenomenon was the Galton dog whistle (1883) which was used to control a dog without producing audible sound. Little else was done until well after the turn of the century. The sinking of the Titanic in a collision with an iceberg in 1912 drew attention to the need for developing a technique to detect underwater obstructions, and this need became more evident in World War I when enemy submarines threatened the Allied Powers with defeat.

Paul Langevin, a former student of Pierre Curie, and Chilowsky (3) succeeded in producing the first piezoelectric ultrasound generator in 1917. They matched the frequency of the alternating field to the resonant frequency of the quartz crystal. The resonance thereby evoked in the latter produced powerful mechanical vibrations which were then transmitted through the surrounding medium as ultrasound waves. The crystal could serve as both generator and detector, since the latter causes mechanical vibrations in the crystal which, in turn, generates electrical charges on its surface.

Langevin lived to see the development of SONAR (Sound Navigation and Ranging) which played an important role in World War II. Although it is uncertain whether this technique contributed much toward submarine detection in the First World War, it certainly played a very important role in the Second World War. The initial generator used continuous ultrasound waves, but it was not until improvements in electronic technology permitted the generation of bursts of ultrasound waves that ranging and detection could be built. The technique is now widely used in determining the depth of waterway channels for navigation, in detecting underwater obstructions, and in locating schools of fish.

Other outstanding early work was done by Sergei Sokolov (4), a Russian scientist. His work at the Leningrad Electro-technical Institute emphasized the potential importance of ultrasound, and he envisioned the many different practical applications but was limited by the lack of technical advances. In 1929, he proposed the use of ultrasound to detect flaws in metals using the through transmission technique. He also proposed the use of ultrasound for use in microscopy, and he experimented with imaging systems using coherent light reflected from liquid surfaces which anticipated Gabon's later discovery of holography. He was awarded the Stalin prize for outstanding contributions to science and is regarded by many as the "Father of Ultrasonics."

The widespread application of ultrasound can be roughly divided into the use of sound waves of high or low intensity. High intensity application refers to those instances in which the purpose is to produce a change or an effect in the medium through which the wave passes. Such instances include: medical therapy, atomization of liquids, machining of brittle metals, welding, certain biological properties, and many others too numerous to list. The therapeutic applications have been described by Ensminger (1) but, unfortunately, have not been vigorously pursued in medicine to date. However, Fry et al. (5), using high intensity focused generators aimed by a stereotactic device, produced destructive lesions in the basal ganglia in cases of Parkinsonism.

The low intensity applications are those wherein the primary purpose is to learn something about the medium or to pass information through it without altering its state. Following the First World War the technology of electronics developed such that it became possible to amplify low amplitude electrical signals and to display these on the screen of a cathode ray oscilloscope. The practical applications include medical diagnosis, nondestructive testing, measurement of elastic properties of materials, livestock judging, underwater depth sounding, echo ranging, communication, and submarine detection, to mention only a few.

Technological advances by 1940 permitted Firestone (6) to develop the reflectoscope for the generation of brief pulses of energy for the detection of the reflections from flaws or fractures from within the castings. This secret device proved very important to the United States in the Second World War and became the basis of the Non-Destructive Flaw Detecting Technique which is used extensively throughout the world today. It is regarded by many as the one development which made medical ultrasound possible.

The first application of ultrasound in medical diagnosis was by a psychiatrist, Dr. Karl Dussik (7), and his brother at a hospital in Bad Ischl, Austria. He tried to locate brain tumors by using two opposing transducers and recording the through transmission of the sound beam. He also wanted to visualize the cerebral ventricles by measuring the attenuation of the ultrasound beam through the head and, in 1942, published the technique, "Hyperphonography of the Brain." Considerable controversy followed a study of his pictures because of the misinterpretation that the skull bone is thinner in the temporal area than elsewhere and thus could simulate the picture of the lateral ventricles (8). These objections led to the cessation of experiments with through transmission techniques. Similarly, a paper presented by Ballantine et al. (9) in 1954 indicated great difficulty in the interpretation of the returning echoes from the various organs and interfaces and claimed it had little value. The through transmission technique for echoencephalography appeared to be a failure following the early work of Dussik and Leksell. Leksell (10), in 1953, was faced with an emergency where there were reasons to suspect a subdural hematoma in a 16-month-old child. He borrowed a Siemens reflectoscope, and, due to the improvement in the performance of the instrument, he was able to detect a clear displacement of the midline echo. This was confirmed at surgery. He proved the usefulness of the shift in the midline echo for diagnosis of expanding processes in the brain which led to further publications with his collaborator, Stig Jeppson. His further work was published in *Acta Chirurgica* in 1956 following which midline echoencephalography was enthusiastically pursued in many centers.

Following Leksell's report in 1956, echoencephalography (M-mode) was investigated on both sides of the Atlantic with a reported high degree of accuracy. The largest series was reported by Schiefer et al. (11), who claimed an accuracy of 99.8% which was accomplished through the knowledge of the history and clinical findings. Kichuchi et al. (12) reviewed the use of the reflection technique to demonstrate reflected echoes from the excised brain and subsequently claimed it was possible to elicit echoes from tumors through the intact skull.

Ambrose (13), in 1964, was one of the first to measure the width of the lateral ventricles by the reflection technique. Ford and McRae (14) used the A-mode display to monitor and follow the width of the lateral ventricles following shunting. Further work in this period was challenged by the difficult technical problems inherent by the skull and the variable thicknesses encountered throughout. Considerable technical progress in overcoming these difficulties has been reported by Barnes et al. (15) from our institution with new instrumentation.

Since 1955, the clinical significance of estimation of the position of the midline echo has been confirmed and elaborated by many investigators, notably in England (Gordon, Jefferson, Ambrose, Taylor, Newell, Karvounis); in Sweden (Jeppson, Lithander); in Holland (de Vlieger, Ridder, Greebe); in Canada (White, Ford, Lee, Morley); in Japan (Juntendo University Research Group); in Switzerland (Müller); in France (Mikol, Fischer); in Germany (Schiefer, Kazner, Brückner, Kramer); and in the United States (Dreese, Grossman, McKinney, Barrows, Sugar).

The Doppler technique, "carotid echography," described by Buschmann in 1964 (16) had extensive application in neurology and has been a stimulus for current development.

It remained the method of study for several years following the introduction of a commercial unit by Spencer and Reid (Dopscan, Carolina Medical Electronics, Inc., King, NC). The interpretation of these studies was difficult, and new types of color-coded display have been developed by White and Curry (17).

The marked improvement in the resolution of real-time scanners and especially the small size of the sector scanner in the late 1970's led to the development of their use in the study of the neonatal brain (18–21). Because of the portability of instruments, its noninvasive nature, and the ease of examination, it has become an extremely useful clinical examination that has developed rapidly over the past few years.

The first published work on the pulse-echo technique was by Ludwig and Struthers (22) from the Naval Research Institute in 1949: "Considerations Underlying the Use of Ultrasound to Detect Gallstones and Foreign Bodies in Tissue." These early investigators were using available surplus war equipment and began to apply ultrasound to medicine and to develop equipment for medical diagnosis alone. By implanting gallstones in the gallbladder of a dog, they showed that this technique could successfully demonstrate the stones.

In the early 1950's there were three areas in the United States where development and research were being conducted. Studies were being conducted by Dr. Douglas Howry at the University of Colorado, Dr. John Wild at the University of Minnesota Medical School, and Dr. George Ludwig at the University of Pennsylvania. All demonstrated that when ultrasound is sent into the body and reaches a tissue interface of different density, echoes will be reflected back to the transmitting transducer. The earliest work used the A-mode display on an oscilloscope.

Edler and Hertz had a very positive influence in Europe following their initial observations with the Siemens reflectoscope in 1953. Leksell, Donald, and Edler produced impressive results in their respective areas of interest. Similar work was done by many investigators in Japan, Austria, Sweden, France, and England, and all have made significant contributions too extensive to discuss here. There was extensive cross-communication between these groups of workers of varied backgrounds, such that each area of applications developed rapidly.

In 1947, Dr. Douglas Howry of Denver, Colorado, began developing forerunners of equipment in use today. He first started application of ultrasound in visualizing the soft tissue structures by displaying echoes from the various interfaces. Using discarded naval Sonar equipment, he developed his first piece of equipment in the basement of his home, which was later transferred to the University of Colorado School of Medicine. There, in 1949, in conjunction with an engineer, W. Roderic Bliss, he developed a successful pulse-echo system which could record echoes from tissue interfaces. In 1952, Howry and Bliss (23) published two-dimensional ultrasonic tomograms using a sector scan of various tissues in vitro and of the forearm in vivo. The principle of compound scanning was introduced in 1951 and consisted of two or more movements of the probe: the beam reached any point in the tissue from many positions of the probe, and the echoes were accurately recorded and integrated. Initial scans utilized the water immersion technique, and a variety of water containers were used, such as a laundry tub, a cattle-watering trough, and a gun turret of a B-29 airplane, which was purchased as scrap. The internal circular-toothed track rotated and carried the transducer smoothly around the subject. Howry tried to image the brain but was disappointed at the lack of echoes; however, he did produce a satisfactory scan of the neck, which is now quite well known. He called the device a "somoscope," because it appeared to be most effective in the study of soft tissues.

The marked disadvantages of the immersion technique soon became apparent and, in 1960, Howry began experimenting with mechanical sector scanners applied to the body surface. This led to the development of a hand-held system with an articulated arm holding the transducer with freedom to scan in several planes. Howry left the University of Colorado in 1962 for reasons of health and worked as a radiologist at the Massachusetts General Hospital until his death in 1969. Much of the work in the development of the scanning arm and technique was carried out by Dr. Joseph H. Holmes. It became apparent that the reflection technique was a more practical method for medical diagnosis. Short bursts of sound were emitted from the transducer followed by a relatively long "listening time," where recordings were made of the amount of sound reflected by the tissue interfaces.

Wild and Reid, of St. Martin's Hospital in Minneapolis, Minnesota, began their work in 1949. In 1951, Wild and Neal (24) published their studies which were aimed primarily at determining the possibility of using ultrasound to detect the differences in normal and diseased tissue by an A-mode display. In 1952, Wild and Reid (25) published two-dimensional scans which included a breast carcinoma, normal kidney, and muscle tumor. Their findings indicated that, in general, cancerous tissue reflected more sound than normal tissue and that the tissue of nonmalignant tumors reflected less than normal tissue. Wild and Reid (26) were responsible for several other significant explorations in the clinical application of this technique. They demonstrated that there was a different echo pattern from the various layers of the intestine; they studied the walls of the sigmoid colon on withdrawal of a transducer placed via the sigmoidoscope and suggested the intragastric placement of a transducer to study the patterns of carcinoma of the stomach. Wild and Reid (27), in 1956, reported their results of examination of 77 palpable abnormalities of the breast. All but one of the 27 malignant tumors had typical echograms; of 50 benign lesions, 43 had an echogram of nonmalignant type and seven of malignant type. Most significantly, they reported a 90% accuracy in the diagnosis of cystic versus solid lesions of various organs using the B-scan technique.

The enthusiasm for the ultrasound technique received a temporary setback by a report published by the United States Atomic Energy Commission in 1955 (28). It concluded there was no possibility of adapting this method for study of intracranial lesions. This had a depressing effect upon workers in the United States, and progress in many areas was slowed considerably. This report was made with little consideration of the type of equipment and energy form used. However, workers in Europe, especially in Scotland and Sweden, were not adversely influenced, and in a brief period of time practically all advances and developments were reported by them. These early states of development in technique closely paralleled many other parameters of electronic technology. This continues even today with the development of digital display, computers, and new transducer materials.

In 1954, Ian Donald, upon accepting the appointment of Regius Professor of Midwifery of Glasgow, became interested in ultrasound and its application in obstetrics and gynecology. He, his engineer, and physician associates made great contributions using borrowed flaw detector instruments. His major interest initially was to compare A-scans to determine whether they could differentiate solid from cystic masses. He took two carloads of large abdominal tumors to the research laboratory of a large firm which built atomic boilers and used flaw detectors on them. He found that the patterns of the solid and cystic lesions were distinctly different, and on this basis the company loaned him a Mark 2 B flaw detector for further investigation. The problem with the unit was that it had an 8-cm "paralysis time" which blanked out the scan for the first 8 cm from the transducer.

Eventually, he contacted the firm making equipment for atomic boilers and convinced the directors to grant him money for his research. In 1955, Mr. Tom Brown, an engineer, began a long association with Dr. Donald. In 1957, they designed and constructed a prototype hand-operated two-dimensional contact scanner which is now used clinically for studies of the female pelvis and abdomen. The transducer probe was in direct contact with the skin and coupled with the use of olive oil. The main advantage of contact scanning was the elimination of the sound-transmitting water tank and its inconvenience. Photographs were made on Polaroid film, and the shutter of the camera remained open during the entire scanning period. The results were first reported in 1958 in the *Lancet* (29). This, he admits, was probably the most important paper that he had written.

Dr. Donald's primary interest was not in obstetrics, but in the differentiation of the truly massive abdomen due to either ovarian cysts or ascites. He had a very dramatic experience with a patient who was thought to have massive ascites due to obstruction from a radiologically demonstrated carcinoma of the stomach. He was called to see the patient and, after the clinical examination, suggested that she be examined by the A-scan ultrasound technque. When he applied the probe to the most protuberant part of the patient's abdominal wall, there were no bowel echoes seen in the area, and only a large echo-free space with a well-defined posterior wall was evident. Following this, the patient was removed to his department for laparotomy, and a massive ovarian tumor was removed. She recovered nicely and remained a lifelong friend. This case marked the beginning of abdominal ultrasonography.

In 1957, pregnancy studies started when Dr. Donald became impressed by the very strong echoes coming from the fetal skull. His engineers provided electronic cursors which could be displayed on the cathode ray tube (CRT) and used to measure the fetal head size electronically. In 1960, he developed the first automatic scanner and demonstrated it, but it proved to be a very expensive instrument. It was developed because overscanning performed by the operator could occasionally produce artifacts. In 1961 (30), he published a paper on the hydatidiform mole and emphasized the extreme importance of the proper scanning technique and the avoidance of artifacts. About this time, Campbell (31) from his group began working on the growth patterns of the fetus as measured by serial biparietal diameters. In 1961 (30), the first diasonograph was demonstrated before the British Institute in Radiology. Donald was largely responsible for developing the contact scanning technique and for pioneering the extensive application of ultrasound in obstetrics and gynecology; to this day, despite extensive cardiac surgery, he remains quite active in this field.

It became important for Dr. Donald to develop his one-dimensional display into a two-dimensional sonogram, which was done with the help of Tom Brown and was first published in 1958 (29). Sunden, in 1958, visited Donald and the Smith Industrial Division in Glasgow where T. G. Brown had built Donald's first machine. His publication in 1964 (32) of a study of more than 400 patients demonstrated the clinical usefulness of the method in obstetrics and gynecology. His report and that of Thompson et al. (33) were of great influence leading to the general acceptance for clinical use today.

Donald's experience emphasized that abdominal scanning can be very informative, and it was widely pursued by many workers. The presentation and recording from the CRT were referred to as "bi-stable," which meant that only strong reflections were recorded, and the picture was white on black with no graduations. This type of presentation, along with the fact that they represented only a thin slice or body section, was initially not attractive to physicians because it was a new presentation to which they were unaccustomed. Nevertheless, many workers made numerous contributions and developed great enthusiasm for the technique.

The introduction of the gray-scale presentation in 1971 (34, 35) proved to be a real stimulus for clinical development. The display was now a little more understandable to physicians for it was no longer white dots on a black background, but rather a pleasant picture with varying shades of gray. This was made possible by the use of the scan converter through which high and low level echoes were displayed as various levels of gray. The introduction of gray-scale echography marked the beginning of clinical acceptance for an ever-increasing variety of techniques. In 1973–1974, considerable attention was given to the visualization of the liver and kidneys. One of the major applications was the visualization of the vasculature of the upper abdomen, which, in 1976, led to a more positive identification of the pancreas.

Wild and Reid attempted transrectal studies of the prostate early in their work, but the scans were so poor they did not report on them. Japanese urologists in 1963 reported A-mode scans of the prostate gland which were somewhat difficult to interpret. Earlier reports by Takahashi and Ouchi (36) in 1963 and 1964 were far from being of practical use because of poor picture quality. Watanabe et al. (37), in 1971, reported ultrasonograms of the prostate using transrectal Plan-Position-Indication (PPI) scanning with a specially prepared concave transducer. Their paper illustrated a wide variety of prostatic disease with good picture quality. His transducer was covered with a water-filled balloon which assured good contact with the rectal wall. The patients were done in the sitting position. The bladder was filled with water and he demonstrated scans of the bladder, prostate, uterus, and seminal vesicles. Holm and Northeved (38) described a transurethral scanner in 1974 which was interchangeable with the optical system of a resectoscope.

King et al. (39) were the first to use the prostate scanner in the United States with good clinical results, and it was further reported by Resnick et al. (40). Initially, the scanning was done in the lithotomy position, but because of problems with air bubbles, most scanning is now done in the prone position. More recently, Hileman (personal communication) has developed transrectal scanning equipment which envelop two transducers in a single probe. He used 3.5 and 7.0 mHz transducers optomized for a range of 10 cm. His unit permits rapid recording on 35-mm film.

More recently, Henneberry et al. (41) and Abu-Yousef et al. (42) have demonstrated the value of B-scans of the prostate gland from the anterior abdominal wall through a full urinary bladder. Prostate size, contour, and margins are readily studied. Real-time scanning has proved to be a rapid and accurate method of prostate gland scanning.

THE DOPPLER EFFECT

A physicist, Christian Johann Doppler, in 1842, predicted that light emitted from a moving source would be changed in frequency and hence in color. Satomura (43) reported using the ultrasound Doppler technique in the study of flow patterns in peripheral arteries in 1959. Franklin et al. (44) in 1961, using two transducers to study arterial flow noninvasively, demonstrated the frequency spectrum of the returned beam to be broadened and used this method to measure the instantaneous flow of blood. These devices measured only amplitude of the returned signal. McLeod (45) (1967) and Pourcelot (46) (1971) designed directional systems which processed the backscattered ultrasonic signals in two separate channels, in which the respective Doppler shift signals are distinguished by a phase shift of 90°. These developments allowed the measurement of blood velocity in a localized area of the vessel lumen and made it possible to measure instantaneous profiles without interfering with flow.

The ultrasonic pulsed Doppler method has been the subject of various developments since 1968. It allows the measurement of blood velocity in a localized area of the lumen of the vessel, and it became possible to measure profiles of instantaneous blood velocity without interfering with flow (47).

Physicians throughout the world recognized and used this new technique to study the cardiovascular system and provided much new information in a noninvasive way. Much of the clinical experience has been related to peripheral vessels as described by Strandness et al. (48), Sigel et al. (49), and Lavenson et al. (50). Their studies on the peripheral arteries and veins have been found to be very useful in many clinical problems.

Continuous wave Doppler has been used by Tajik et al. (51) and Yoshida et al. (52) to examine the heart. The early work was used to obtain signals from the heart wall and valves by Kostis et al. (53) Huntsman et al. (54) have found this technique to be useful in studying the velocity of blood flow in the aorta and relating it to cardiac output.

Obstetrical Doppler applications were reported by Callagan et al. (55) in 1964, when they detected the movement of the fetal heart. Others found it possible to hear the fetal heart at about 12 weeks, and it was also found to be helpful in the localization of the placenta. It is used to detect fetal death as well as in the new area of continuous fetal monitoring.

Buschmann (16) (1964) decribed "carotid echography" for the diagnosis of carotid thromboses. The two walls of the carotid artery could be demonstrated and registered continuously; however, development of such ultrasonic Doppler has been slow since it proved difficult to separate and identify signals originating from the carotid and its branches. In 1971, Hokanson (56) first made spatial displays of the carotid bifurcation by means of a pulsed Doppler system. Reid and Spencer (Dopscan, Carolina Medical Electronics, Inc., King, NC) developed the first commercially available instrument with which it was possible to find occluded segments of the carotid bifurcation which do not appear on the image.

White and Curry (57) have reported a system which directly displays those regions from which higher frequency Doppler shifted signals are recorded with an appropriately coded color display. Additional techniques have used the real-time scanners and superficial scanners recently developed by several companies.

One of the most interesting developments was by Baker and Johnson (58) with the introduction of the pulsed Doppler cardiac technique.

This permitted the recording of valve movements as usually seen in routine echocardiography with the addition of a superimposed display and location of the Doppler signal. This technique, with simultaneous display of the two signals, provides for echo ranging and the location of various cardiac structures as well as sampling specific areas within the heart.

Considerable attention has been given the combination of a real-time cross-sectional system coupled with pulsed Doppler (59). Although this system was designed with cardiac studies in mind, it has found many other areas of application, especially in the abdomen where positive identification of arteries and veins can be made. Although this combination has only recently been developed and become available commercially, it is highly probable that this type of instrument will become the instrument of the future in certain areas.

The most recent development using the Doppler principle is the development of an instrument (MAVIS) (60) using 30 channels of pulsed Doppler simultaneously in order to differentiate arteries and veins by a simultaneous color-coded readout. It uses microcomputers to calculate mean blood flow in milliliters per minute and velocity profiles in selected portions of the artery during the cardiac cycle.

REAL-TIME

Real-time imaging probably originated with the advent of "compounding" which was really intended to add new information to the scan. Such a unit was built by Homes and his group at the University of Colorado to produce compound scanning in 1962. They used a small motor to rock the transducer five times per second back and forth on the patient's skin. The long phosphordecay left enough image on the screen to see the entire field as the brain swept back and forth. This represented a primitive real-time scanner and led to the development of several different instruments.

Kretztechnik of Austria in 1965 was commissioned by Dr. Werner Buschmann (16), an ophthalmologist, to build a 10-element phased array transducer. It was used to scan the eye, arteries, and other structures, but like all systems of that period it suffered from lack of sensitivity and poor video processing. This probably represents the first effort to build a dedicated real-time scanner. The resolution, however, was poor.

Kichuchi et al. (61), in 1966, introduced "synchronized ultrasonocardiotomography" which was used to obtain studies in nine different phases of the cardiac cycle. This system used a mechanically rotating transducer and a water path to obtain sector scans of the heart.

Somer (62), in 1968, reported the development of an electronic scanner for ultrasonic diagnosis. He used a 21-element array, of 1.2 MHz capacity, made of lead zirconate titanate. The array could be excited as a single unit, or each transducer could be excited in a sequential manner or in many combinations. The frame rate was 30 per second, and it produced a "real-time" image. The pulsations and the vessels of the brain could be demonstrated, but, because this was only a minor part in the diagnosis of intracerebral disease, it was not exploited. His system did, however, present a real-time image which was the first with a reasonable display.

Patzold et al. (63), in 1970, employed a rotating two-transducer sound source and a cylindrical parabolic mirror to produce images at about 15 frames per second. The unit was used extensively in Europe despite the flicker in the display.

Hertz and Lundstrom (64) also described a fast ultrasonic scanning system for heart investigations using a mirror system.

Bom et al. (65), in 1971, introduced a fast scanning system for the heart having good resolution and producing images in real-time which could be directly observed on the screen of a CRT. His transducer contained 20 small ultrasonic elements approximately 3 mm in diameter which were fired in rapid sequence.

Griffith and Henry (66), in 1974, developed a mechanical scanner which oscillated a standard transducer through either a 30° or 45° sector with a display frame rate of 30 per second. The quality of the scans obtained was considerably better than the multielement systems.

Other units have been developed, but probably the most sophisticated is the phased array principle developed by Thurstone and von Ramm (67). This technique employs multiple elements in the transducer, fired in a rather complicated sequence by a computer, to sweep electronically through a sector. New aditions are being made continually to improve range, focus, resolution, etc.

Real-time scanners are classified either as (*a*) mechanized or (*b*) electrical. The mechanical scanners have transducers which are either fixed