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Special Feature

Diagnostic Ultrasound During the Early Years of A.I.U.M.

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In August, 1951, 24 physiatrists met in a hotel room in Denver to discuss the formation of an organization to promote the use of ultrasound in physical medicine. Ultrasound equipment manufacturer, Cecil Bircher, presented to that group reports of seven years' experience in Europe with the use of ultrasound in physical medicine for treatment of a variety of muscular disorders. The following year in New York the group was formally organized as the American Institute of Ultrasound in Medicine. Dr. Disraeli Kobach was its first president; Dr. John Aldes, its first executive secretary. The group usually met annually at the American Congress of Physical Medicine, with a total attendance reaching approximately 350 at these meetings. Initially, membership included only physiatrists. In 1964, at the presidential address at the Boston meeting, Dr. Carrie Chapman welcomed into A.I.U.M. all physicians and bioengineers who were interested in the medical applications of ultrasound, particularly those in the diagnostic field. Membership increased rapidly in the 1970s and now has reached a total figure of 3,800 as A.I.U.M. approaches its 25th anniversary meeting.

Each member of the original group was generously supplied by Mr. Bircher with ultrasonic therapeutic equipment for use in their departments of physical medicine. As a result, this equipment was put on the American market in 1953 and received considerable support from the clinical experience described by the original group members.

My purpose is to discuss the status of diagnostic ultrasound during the early years of A.I.U.M. At the time, the only reported diagnostic work using ultrasound waves introduced through tissue had been that of Dr. Karl Dussik in 1942 *(1)*. He started with a "through transmission" technique, sending the ultrasonic energy through the transmitting and receiving transducers which were placed on opposite sides of the head. He was the first to claim that by mapping the changes in attenuation through the brain he could detect intracranial tumors. Dr. Dussik called these attenuation maps *hyperphonograms*.

The development of metal flaw detectors and naval sonar during World War II made it possible in the late 1940s for three independent investigators to demonstrate that as ultrasound waves were sent into the body, echoes would return to the same transducer by reflection from tissue interfaces of different density. The three were Drs. George Ludwig, Douglas Howry, and John Wild.

Ludwig, a graduate of the University of Pennsylvania School of Medicine, had been pursuing a career in surgery *(2)* and was interested in ultrasound's potential to detect gallstones. Some of his original ultrasonic work was done at the Naval Research Medical Institute and at the University of Pennsylvania. When he assumed the duties of a surgical residency at Massachusetts General Hospital, he worked with R. Bolt and T. Hueter in the Bioacoustics Laboratory at the Massachusetts Institute of Technology. One of his most significant contributions was the measurement of a velocity of sound transmission through soft tissues *(3)*. Figure 1 shows several sophisticated measurements he made on tissue. Ludwig also showed that transmission through gallstones varied tremendously, from 1,400–2,200 m/sec. He followed this work with the surgical introduction of stones into the gallbladder of dogs. In an early article he discussed the difficulties related to the practical clinical value of this technique, particularly those associated with marked attenuation of sound produced by gas-filled intestines.

Dr. Douglas Howry started his investigative work with diagnostic ultrasound about 1948, literally in his basement. He worked first with Rod

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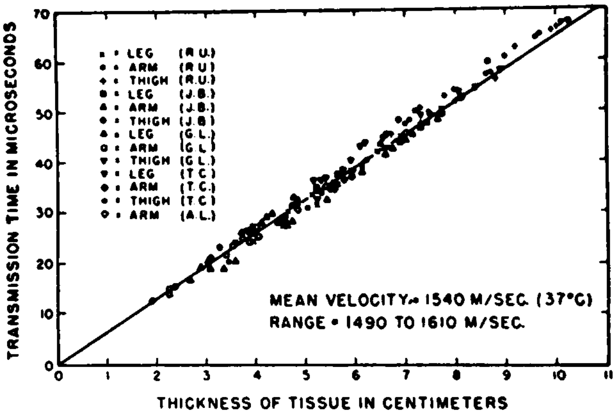

FIGURE 1. Measurements of the velocity of sound transmission through a variety of soft tissue which consists principally of muscle. Chart made by Dr. George Ludwig in 1949. The line is the best straight-line fit of all data taken on living human tissues. (Reproduced from progress report to the Office of the Naval Medical Research Institute.)

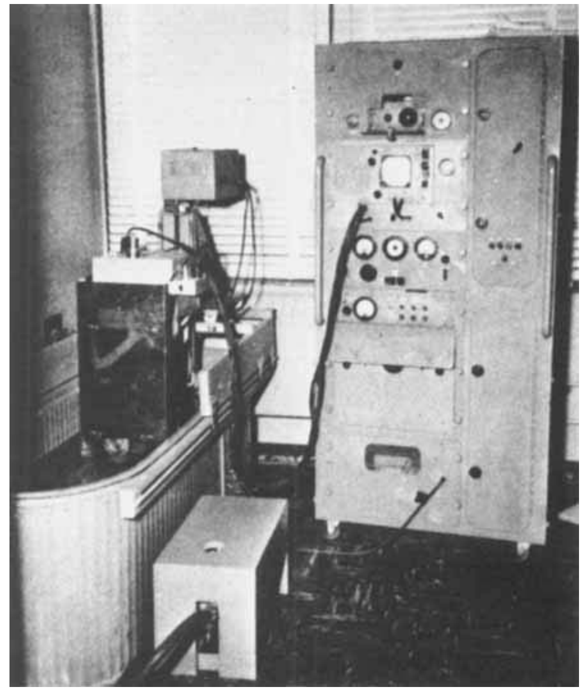

FIGURE 2. Cattle tank scanner developed by Dr. Douglas Howry and volunteers. The transducer carriage moves on the wooden rail along the side of the tank. (Reproduced with permission from Trans Am Clin Climatol Assoc 66:208, 1954.)

Bliss, an engineer from Denver Research Institute and Decimeter, a small Denver electronics firm *(4)* and then also with Jerry Posakony, an engineer. Their early work demonstrated that an ultrasonic echo interface existed between fat and muscle and that the returned echoes could be recorded on a scope. Howry's goal was to develop this new echo technique to display anatomical structures which could be utilized and interpreted in the same way as an X-ray or other imaging techniques *(5)*.

In developing a water path scanner, Howry used a laundry tub and then a cattle tank (Fig. 2). The subject's extremity was placed in the water and the transducer carriage moved along a wooden rail at the side of the tank. This produced, however, an incomplete image (Fig. 3). Although some of the arm's anatomical structures could be identified, the echo picture lacked a two-dimensional appearance which would have been easier for the average physician to recognize. I started working with this University of Colorado group in 1950.

Their next step was the development of compound scanning. This scan required moving the transducer in two different motion patterns simultaneously. It eliminated most artifacts and permitted recording curved or angular tissue interfaces, thus producing a more complete anatomical picture than that shown in Figure 3. The B-29 gun turret scanner was constructed at Denver University Research Center and modified under the direction of Howry and Posakony. The electronic equipment, display unit, and B-29 gun turret are shown in Figure 4 *(6)*. For a neck scan, the subject sat in the tank with a weight on his

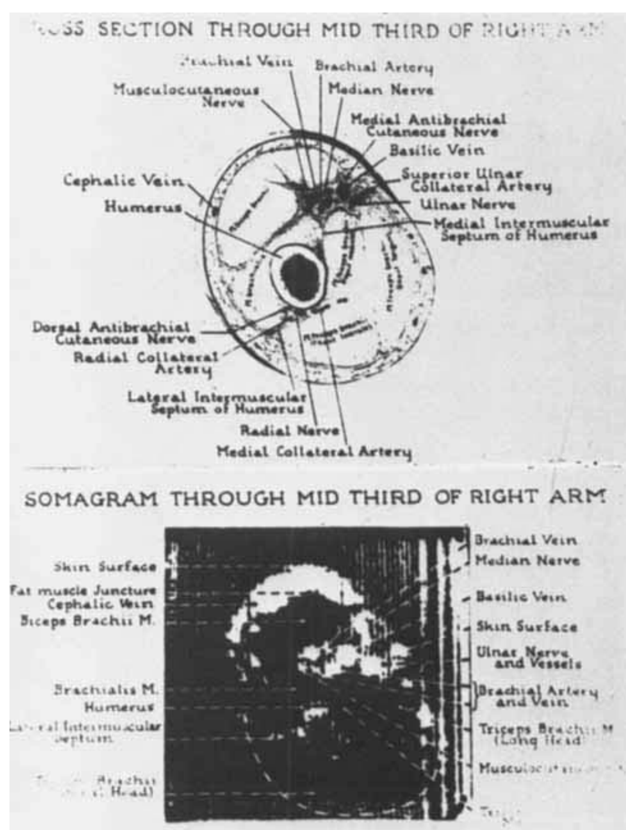

FIGURE 3. Scan of a forearm made with the scanner shown in Figure 2 is compared with ultrasound anatomical cross-section. While some structures can be identified, anatomical structures farther from the transducer are poorly delineated. (Reproduced from progress report to VA Central Office, 1951.)

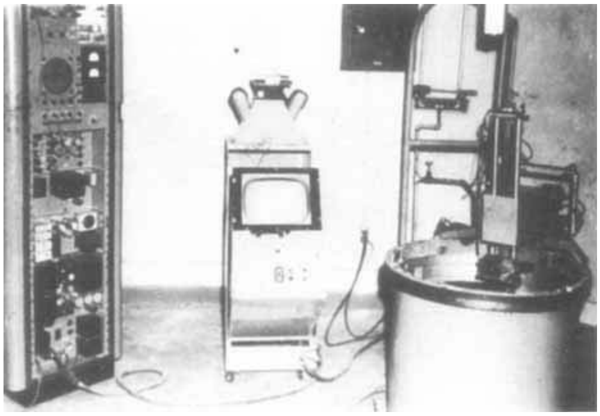

FIGURE 4. B-29 gun turret scanner with electronic equipment is shown on the left, the display unit in the center, and the B-29 gun turret with rotating transducer carriage on the right. (Reproduced with permission from Trans Am Clin Climatol Assoc 70:235, 1958.)

abdomen (Fig. 5) *(7)*. Figure 6 shows a complete scan in contrast to the initial four quarter section scans, which had to be pasted together to make it complete. Even when compared with scans made by the most recent equipment this scan gives a good picture of the anatomy of the neck. Through use of a P90 phosphor, this display had a form of gray scale, which faded proportionately to its original echo intensity.

Anatomical echo patterns proved accurate. For example, an ultrasonic scan of a lower leg was performed before amputation. Following amputation the leg was frozen, sectioned at the same level, and then the anatomical picture and the ultrasonic image of the leg were compared (Fig. 7) *(6)*.

A different echo pattern displayed disease pro-

FIGURE 5. For scanning the neck, subject is immersed in the tank and a lead weight lies on his abdomen to prevent floating. The transducer carriage circles the neck. (Reproduced with permission from progress report to HEW, 1956.)

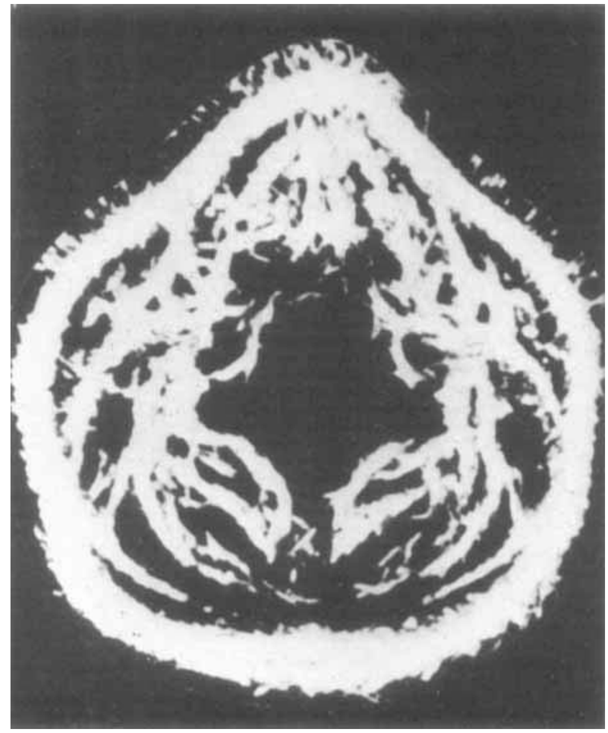

FIGURE 6. Neck scan obtained with equipment shown in Figure 5. The anatomical detail shows vessels, muscles, larynx, etc. (Reproduced from progress reports to National Institutes of Health.)

cesses. Figure 8 shows two human liver specimens, one normal, the other cirrhotic *(8,9)*. The corresponding ultrasonic scan is on the left. The significant increase in echo patterns in the cirrhotic liver corresponds with the diagnosis.

Since the B-29 water tank was impossible to use for sick patients, the next step was to simplify the compound scanner technique. It employed a semicirculator pan with a section removed from its flat surface and had plastic sheeting inserted over the hole (Fig. 9) *(9,10)*. Mineral oil was put on the patient's skin to provide sonic contact when the patient was strapped against the plastic window. A dental chair raised and lowered the

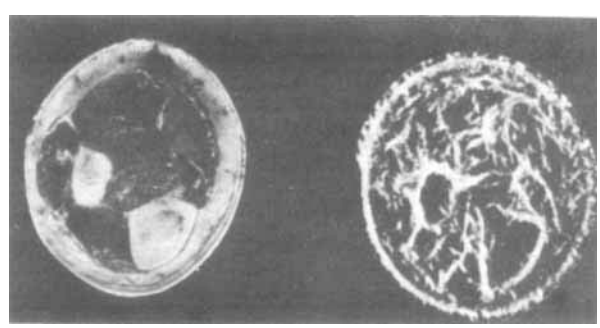

FIGURE 7. Ultrasonic scan (right) of the lower leg. After amputation, the specimen (left) was frozen, sectioned at the same level and compared for detail with the ultrasonic pictures. (Reproduced with permission from Trans Am Clin Climatol Assoc 70:235, 1958.)

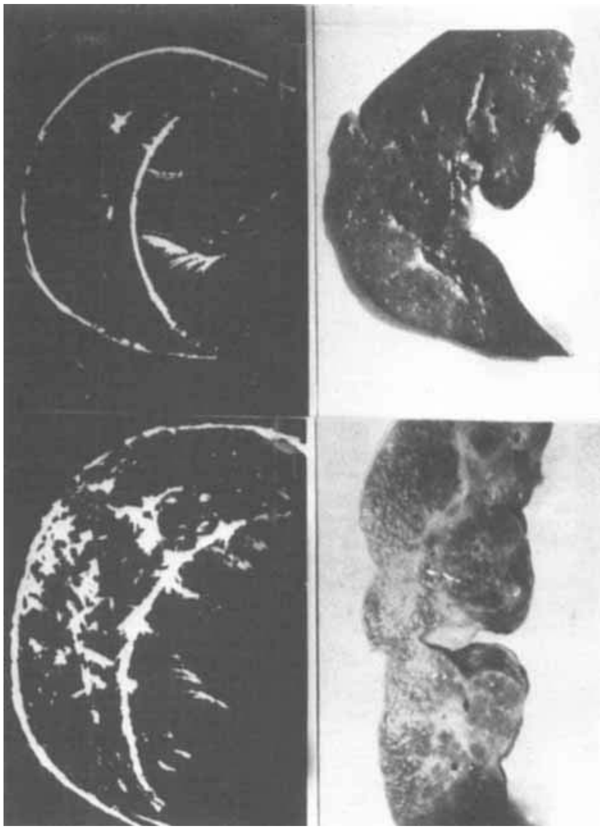

FIGURE 8. Two human liver specimens, one normal (upper) and one with cirrhosis (lower) are compared to the corresponding ultrasonic echo scan. (Reproduced with permission from Grossman CC, et al (eds): Diagnostic Ultrasound. New York, Plenum Press, 1967, p. 253.)

patient at preselected distances. The scanning carriage moved in a semicircular path and the transducer moved simultaneously in a horizontal 4-in path. This type of equipment provided good scans of the liver, spleen, kidney, and bladder. It was used clinically, especially for the detection of liver abscesses and cysts. Figure 10 shows a scan of the normal liver and kidney made with this scanner *(8)*. The liver has diffuse echoes throughout, whereas the kidney parenchyma behind it is sonolucent except for echoes from the calyces.

It was possible to obtain excellent breast scans by cupping the plastic sheet and positioning the patient against the sheet. Carcinoma of the breast could be demonstrated easily. Polycystic kidney disease could also be demonstrated by using the pan scanner. Both liver and kidney cysts could be displayed. With the patient in a sitting position, it also produced good scans of the bladder.

Following the development and clinical use of the pan scanner, the University of Colorado group did not produce much new equipment for several years. Their major accomplishments were the improvement and expanded clinical use of the existing equipment. Howry felt that the nonspecificity

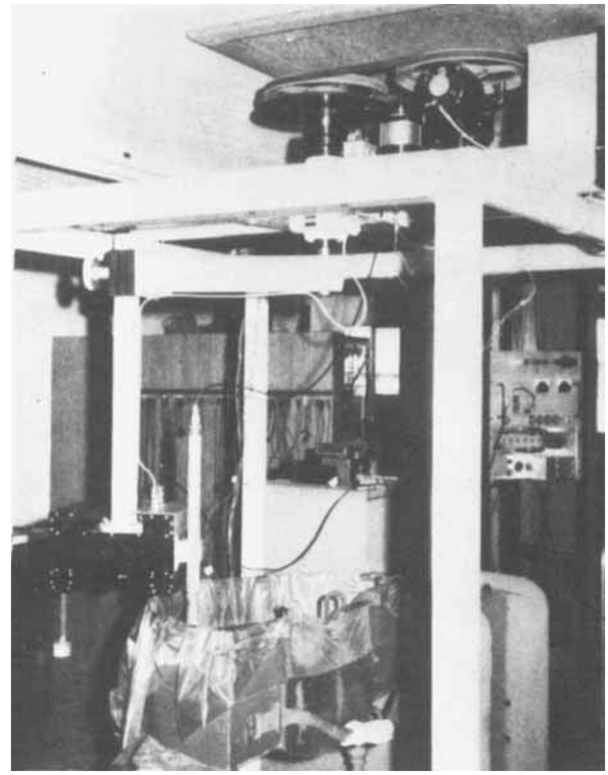

FIGURE 9. The half-pan scanner with overhead mechanical scanner. (Reproduced with permission from Biomed Sci Instrum 2:11, 1964.)

of the echoencephalograph and echocardiograph applications argued against building equipment for this purpose. It wasn't until 1960–61 that such equipment was constructed by William Wright at the University of Colorado Medical Center.

Dr. John Wild was very active in the early development of ultrasound for diagnostic purposes.

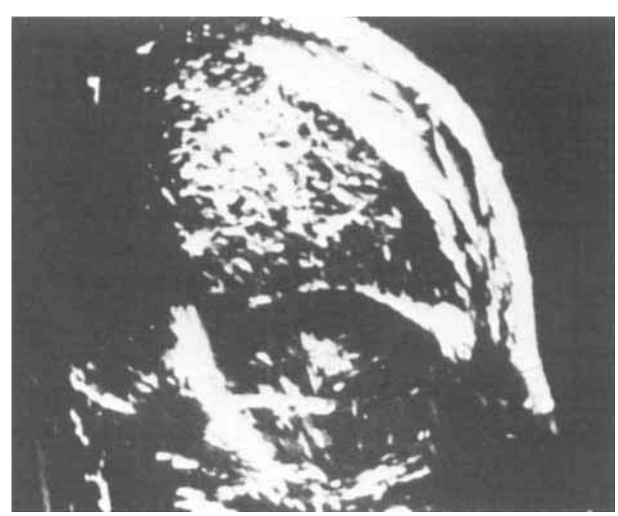

FIGURE 10. Scan of a liver and kidney made with the half-pan scanner. (Reproduced from progress report to HEW, 1954.)

As a member of the surgical department at the University of Minnesota, he initially became interested in measuring the thickness of the intestinal wall *(11,12)*. He had already demonstrated that echoes could be displayed from a musculo-fat interface using ultrasonic equipment acquired on loan from the Navy at Chamberlin Field. In vitro study of intestinal thickness was simple, and the calculation of wall thickness was based on the rate of sound transmission and the ultrasonically measured distance between anterior and posterior wall echoes. In one of his classic in vitro experiments using a strip of cancerous stomach, he suddenly realized that the echo pattern from the normal tissue and from the carcinoma differed significantly (Fig. 11). About that same time Wild also demonstrated three different echoes from the intestinal wall, and assumed they represented three different layers of the intestine. He then began to demonstrate an echo difference for tumors in brain specimens and eventually in living brain after a bone flap had been removed.

Wild and John Reid concentrated their clinical interests on diagnosis of breast lesions. Using both A mode and B scan, they demonstrated that the echo pattern in breast tumor differs significantly from that of normal breast tissue *(13)* (Fig. 12). One of their initial B-mode scanners is shown in Figure 13. The transducer is moved

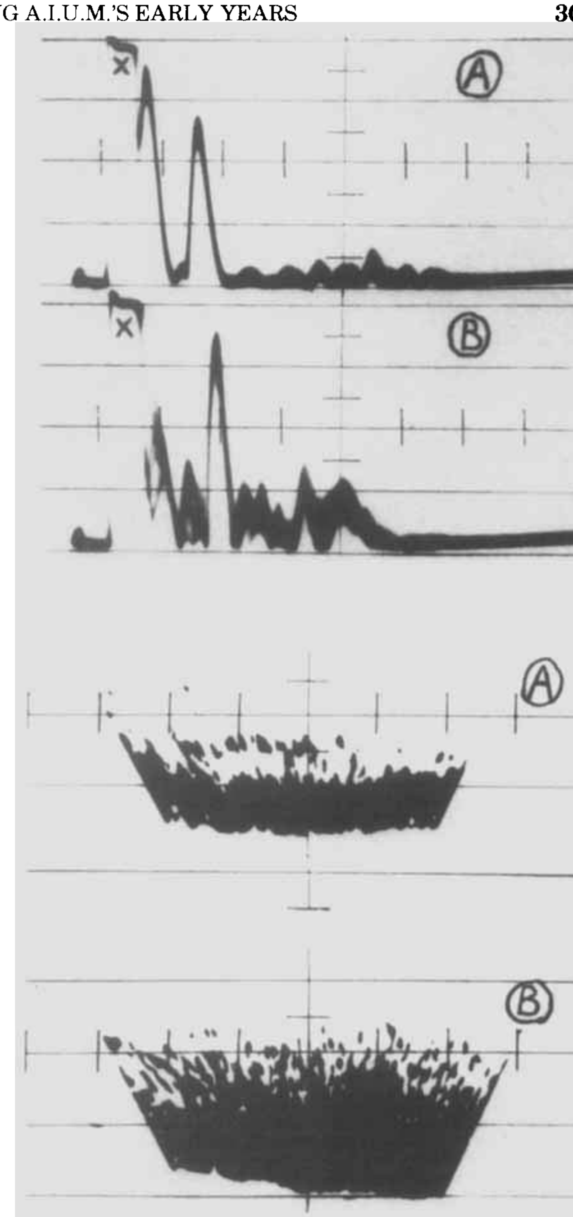

FIGURE 12. The upper two pictures show A-mode displays of normal tissue (A) and cancerous breast tissue (B). The lower two pictures are compound scans of normal and cancerous breast tissue. (Reproduced with permission from Am J Pathol 28:839, 1952.)

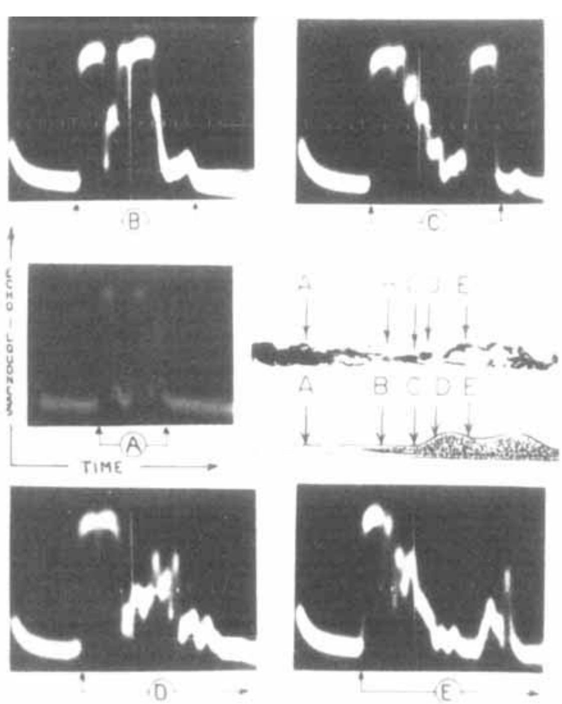

FIGURE 11. A-mode scans of a stomach section containing tumor at one end to compare echo pattern over normal and cancer tissue. (Reproduced with permission from Cancer 4:332, 1951.)

along the surface of the skin. The sector scan was achieved by an eccentric wheel.

Several other types of breast scanners were developed. One was what Wild termed a "hermetically sealed" tank. The subject laid across the top of the tank with a breast suspended within the tank. Another model employed a rotating transducer moving below both breasts which were suspended in a water tank. This provided simultaneous scans of both breasts. He also developed a scanner with two transducers, each moving horizontally underneath a single breast, but with the scan so integrated as to provide a picture of each

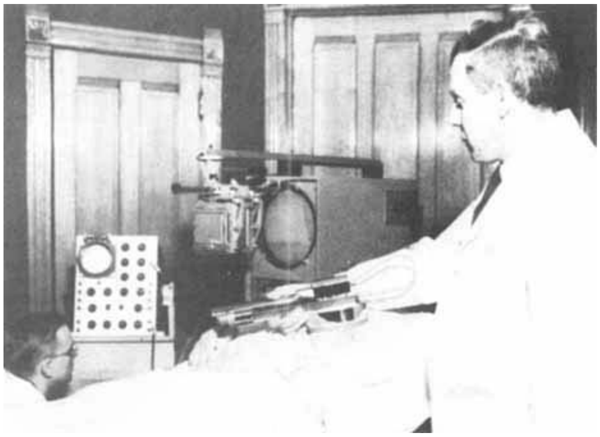

FIGURE 13. Dr. John Wild is seen using a surface scanner his group developed for breast examination. (Courtesy of Dr. Wild.)

breast simultaneously. Another approach used by Wild was a transducer moving in a back-and-forth scan above the two breasts. A plastic window in the floor of the water bath provided sonic contact. According to Wild, the major use of ultrasound for the breast studies was in mass screening for detection of early breast tumor.

In 1955 Wild developed a rectal scanner. The transducer was inserted rectally, rotated, and then withdrawn in a planned scanning pattern, thus visualizing tumor of the large bowel.

He also constructed a double transducer scanner for the study of the heart. A yoke holding both transducers fit over the shoulder, thus the sending and receiving transducers were placed on different sides of the chest.

It should be emphasized that Wild was the first person to envision ultrasound as a method for tissue characterization rather than as an imaging technique which presented an anatomical echo picture, as Howry envisioned it. Wild felt ultrasound's future lay in the area of differentiating tumor tissue, determining whether or not the tumor was benign or malignant, and plotting the course of treatment. In 1956 he published an article in the *American Journal of Pathology* describing a study of 117 cases of breast nodules; the accuracy of diagnosis for the series was greater than 90%. Although many of his equipment developments were aimed at mass screening patients, this was never successful to the point of wide acceptance *(13,14)*.

In 1954–55 Dr. Ian Donald of Glasgow, Scotland, initiated his studies of diagnostic ultrasound. One of the most momentous days of his life occurred when he took pathological specimens to an atomic boiler plant outside Glasgow to examine them with a flaw detector. He became convinced that tumor tissue had a different echo pattern than normal tissue. He borrowed A-mode equipment from Dr. Mayneord at the Royal Marsden Hospital, England and used it for detecting ovarian cysts, ascites, and hydramnios *(15)*. His most successful work with the A mode was measurement of the biparietal diameter of the fetal head, thus making it possible to estimate fetal weight and assess the rate of fetal growth *(16)*.

In 1957 Dr. Donald and Tom Brown, an engineer at Kelvin Hughes, constructed a contact-compound scanner *(15)*, which was mounted on a bedside table and suspended over the patient (Fig. 14). To obtain a scan, the transducer was manipulated by hand underneath the bedside table. Figure 15 shows the type of scan obtained. The fetus is on the left; the dark sonolucent area representing amniotic fluid occupies the rest of the uterus.

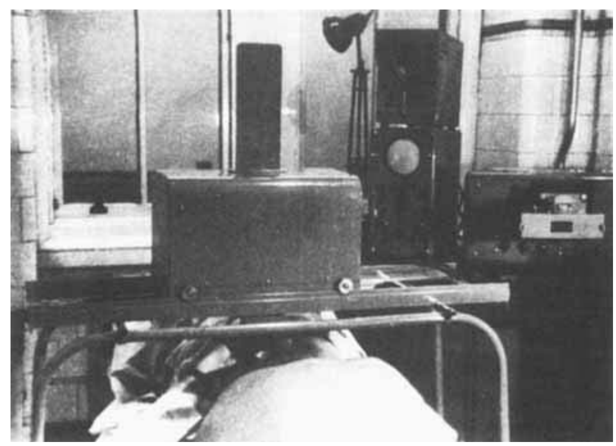

FIGURE 14. First contact-compound scanner developed by Dr. Ian Donald and Tom Brown in 1975. (Reproduced with permission from Lancet 1:1188, 1958.)

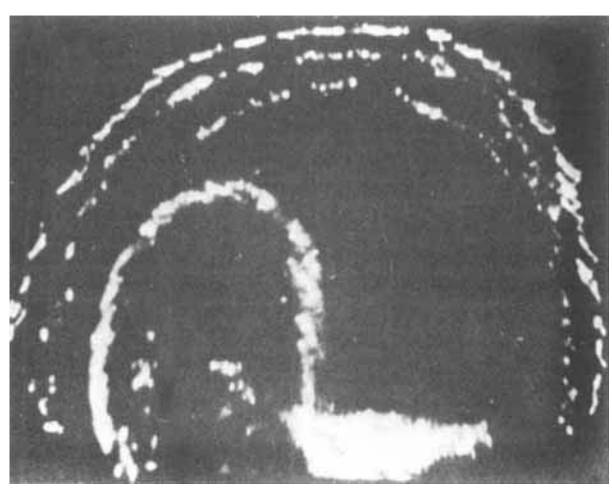

FIGURE 15. Scan obtained with Donald's contact-compound scanner. The fetus is seen on the left; the amniotic fluid is seen as a dark sonolucent area on the right. (Courtesy of Dr. Donald.)

The pictures were still crude but provided more specific information than did A mode.

In 1960 Donald and Brown developed equipment that used a mechanical scanner for the sector scan. Following this, they developed a hand scanner, called the *Diasonograph* (Fig. 16). Twelve of these scanners were produced for commercial distribution, one of which was sent to Dr. Bertil Sunden in Lund, Sweden. The clarity and anatomical display of the central nervous system was definitely improved. Subsequent equipment from this group had the same general appearance *(17)*.

Donald's primary interest was in applying ultrasound clinically. He is well recognized for his contributions to the ultrasound diagnosis of multiple pregnancies, hydramnios, hydatid mole, and early pregnancy (using the fluid-filled bladder technique).

After World War II, a bioengineer, Dr. R. Bolt, was appointed head of the Bioacoustics Laboratory at Massachusetts Institute of Technology. Dr. T. Ballantine, then working in the neurosurgical department at Massachusetts General, showed him articles describing the ultrasonic work being done by Dr. Dussik in Austria, who claimed success in the diagnosis of intracranial lesions. As a result, Ballantine, Bolt, and Hueter, who was then an engineer with Siemens, journeyed to Austria to observe Dussik's work, and they were very impressed by the potential medical applications of ultrasound.

Hueter and Ballantine, with financial support from the Public Health Service, set up a project to establish the value of ultrasound as a diagnostic tool in neurosurgery. After some initial experiments, they put a skull in a water bath and showed that the ultrasonic patterns Dussik had been obtaining in vivo from the heads of selected subjects were the same as those obtained from the empty skull. It was apparent then that reflections within the skull and attenuation patterns produced by the skull were contributing to the attenuation pattern which Dussik had originally thought represented changes in acoustic transmission in the brain. Therefore, they decided that the only feasible approach was to use computer analysis. They developed this technique over a two-year period and felt they could demonstrate changes in attenuation within the brain using through transmission with a sending and a receiving transducer on opposite sides of the head. To achieve this goal, however, the equipment and the time required were unacceptable, according to Bolt. Therefore, they stopped their work on diagnostic ultrasound, describing their findings and their reasons for dropping the program in a classic paper *(18)*.

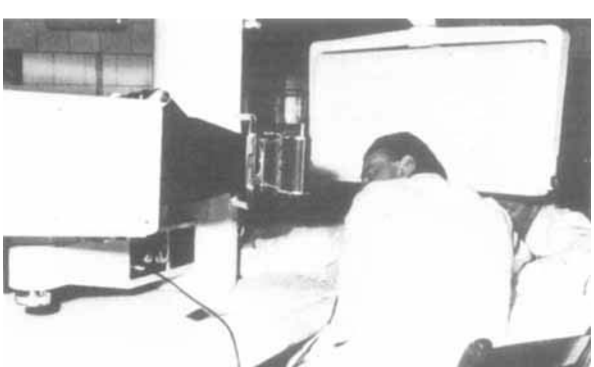

FIGURE 16. Diasonograph constructed in 1962 by Smith Industries for Dr. Donald was used for several years. (Courtesy of Dr. Donald and John Fleming.)

In 1954, in Lund, Sweden, Leksell *(19)*, using a Siemens flaw detector borrowed from Drs. C. Hellmuth Hertz and Inge Edler, first demonstrated successfully the detection of midline shifts in the brain using a pulse-echo technique. The techniques of echoencephalography were developed and its clinical use was expanded by many physicians, including Jepson and Lithander in Sweden, and Jeffries, Gordon *(20,21)*, and Mayneord in England. Dr. Marinus de Vlieger in Rotterdam started his work with echoencephalography in 1958 *(22)*.

During the 1950s the team headed by Dr. William J. Fry of the University of Illinois School of Electrical Engineering was very active in studying the medical applications of ultrasound. Fry had worked during World War II at the Office of Naval Research in the field of atomic energy and planned to continue with this work at Illinois. Since this was infeasible, he shifted his interest to ultrasound. Initially, he obtained a grant to use ultrasound to produce pinpoint lesions in the brains of cats and then study the changes in neurological function associated with such lesions *(23)*. The production of experimental neurological lesions was accomplished by use of a series of three to five focused transducers all directing energy at a single spot in the brain (Fig. 17). The amount of ultrasonic energy produced by each was not sufficient to destroy normal tissue in the path of that particular beam but did result in tissue destruction at the point of mutual focus.

This work led in 1957 to the establishment of a program at the University of Iowa under the direction of Dr. Russell Meyer, a neurosurgeon. By using this technique the group produced pinpoint lesions intracranially for the treatment of Parkinson's syndrome in humans. The same tech-

FIGURE 17. Dr. William Fry is shown with the transducer array he developed for producing pinpoint lesions in the central nervous system in animals and man. He is aiming four ultrasonic generators so that their beams are focused on a single point. (Reproduced with permission from University of Illinois Press, Urbana, IL.)

nique was also used for destruction of brain tumor by ultrasound.

Since knowing where the anatomical lesion has been produced is important in the animal work, the group spent much time detecting by pulse-echo the precise site of the lesion. Using compound B-scan equipment, this method was feasible only when a bone flap had been removed, not in the intact skull.

An important discovery by the University of Illinois group was that pulse-echo visualization could be improved when tissue adjacent to the lesion was heated, thus changing the velocity of sound transmission and acoustic impedance. They developed a two-transducer system, one for heating, the other for pulse-echo detection of the produced lesion. Those working with Dr. Fry included his brother, Frank Fry; his wife, Elizabeth Kelly Fry; Reginald Eggleton; Floyd Dunn; and William Heimburger.

The other significant contribution of this group was that it held several ultrasonic conferences throughout the 1950s and early 1960s. Conferees, who included investigators from around the world, presented papers pertaining to a variety of medical applications of diagnostic ultrasound.

In 1956 Drs. H. Mundt and W. F. Hughes described the use of A-mode ultrasound for diagnosis of an eye lesion. Their studies stimulated two other investigators, Dr. Oksala, working in Finland, and Dr. Gilbert Baum, in New York. Oksala described a series of studies done in the late 1950s using A mode in which ultrasound provided definitive diagnostic information, especially in evaluating foreign bodies in the eye *(24)*. Baum, who was more interested in displaying lesions such as tumors, believed that A-mode techniques were of limited value. Working with Dr. Ivan Greenwood of General Precision, they devised several successive compound scanning units *(25)*. All used a water-path goggle system for examination with frequencies of 7–15 MHz, and both sector and compound scanning. Figure 18 shows the first of Baum's ophthalmic compound scanners.

Baum was successful in demonstrating tumors in the posterior intraocular tissues and describing their size, configuration, and anatomical location. Three other ophthalmologists contributed significantly to further developments of the use of diagnostic ultrasound in ophthalmology. These early investigators were: Dr. E. Purnell at Case Western Reserve University in Cleveland, Dr. W. Buschmann in Germany, and Dr. Karl Ossoinig in Vienna, Austria and later in Iowa City.

Echocardiography started in Sweden in 1954 when Drs. Hertz and Edler borrowed a flaw detector from the Malmo Ship Yards and used intensity modulation and motion displays as wave patterns to demonstrate intracardiac structures. They showed multiple motion patterns within the heart *(6)*. Their initial equipment is shown in Figure 19. They were more successful after they obtained a Siemens flaw detector which was more sensitive. One of their early problems was identification of the various motion patterns. It was only after Edler established the characteristic motion pattern for the anterior leaflet of the mitral valve that the diagnostic potential of echocardiography was realized.

During the year Hertz spent at Siemens he constructed additional equipment, one unit went

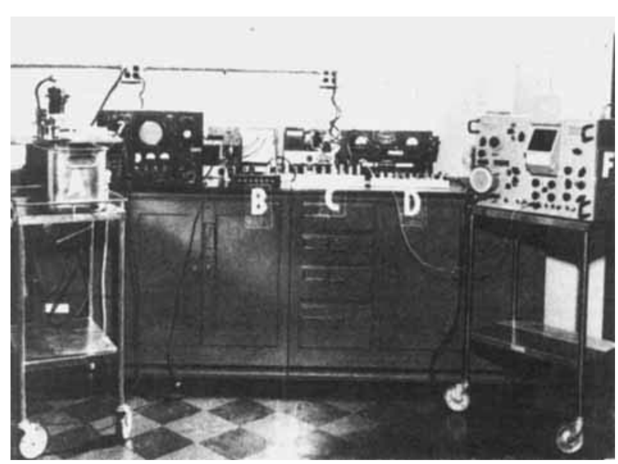

FIGURE 18. First compound scanner developed for ophthalmology by Dr. Gilbert Baum in the late 1950s. (Reproduced with permission from Dr. Baum.)

FIGURE 19. Drs. Hertz (left) and Elder (right) at the time they received the Lasker Award (1979) standing beside the early flaw detector for modified examination of the heart (1954). (Reproduced with permission from Lasker Foundation.)

to Dr. Sven Effert *(27)*. It was Effert who placed a transducer directly on the heart and verified previous identifications of the intracardiac motion patterns. Not until 1960 did Dr. Claude Joyner at the University of Pennsylvania, and Dr. Howry and I at the University of Colorado, construct the first echocardiographs in this country. Dr. John Reid worked on the technical aspects with Joyner, and William Wright worked with me. The first commercial echocardiographs were manufactured by SmithKline in 1964.

Interestingly, the Japanese work in diagnostic ultrasound, started in 1950, roughly paralleled the developments in Europe and the United States. The initial equipment used was designed for detecting schools of fish rather than for flaw detection. Considerably more was done in Japan with the Doppler for examination of the heart in the 1950s than was done in Europe or the United States. This work was done by Drs. Nimura and Satamoto in 1955. Also, much was accomplished in echoencephalography by such investigators as K. Tanaka, T. Wagai, and M. Oka *(28)*. One other area in which the Japanese were ahead was the development of rectal scanners, which were more effective than those developed here for the examination of prostate, bladder, and seminal vesicles. The development of a transurethral scanner in Denmark took quite some time, but has proved quite effective.

During this period, two additional applications of ultrasound proved interesting. One was the use of ultrasound to destroy nervous tissue and to treat Meniere's syndrome, which was first tried by Dr. Arslan. However, George Kossoff, who first started working with diagnostic ultrasound at the Commonwealth Acoustic Laboratories in Sydney in 1959, also did some of his earliest ultrasonic work in developing ultrasonic generators for this application. Later, with the help of Dr. T. Garrett, he constructed a compound water path scanner and conducted excellent work in the early applications of diagnostic ultrasound in obstetrics *(29)*. Figure 20 shows the first compound B scan, Mark I, constructed by the Australian group. Drs. Uchida and Oka in Japan proposed another unusual application for ultrasound: shattering renal stones. Special apparatus was built for this purpose, and the amount of ultrasonic energy required to fracture stones was studied.

I hope that this provides an overview of the

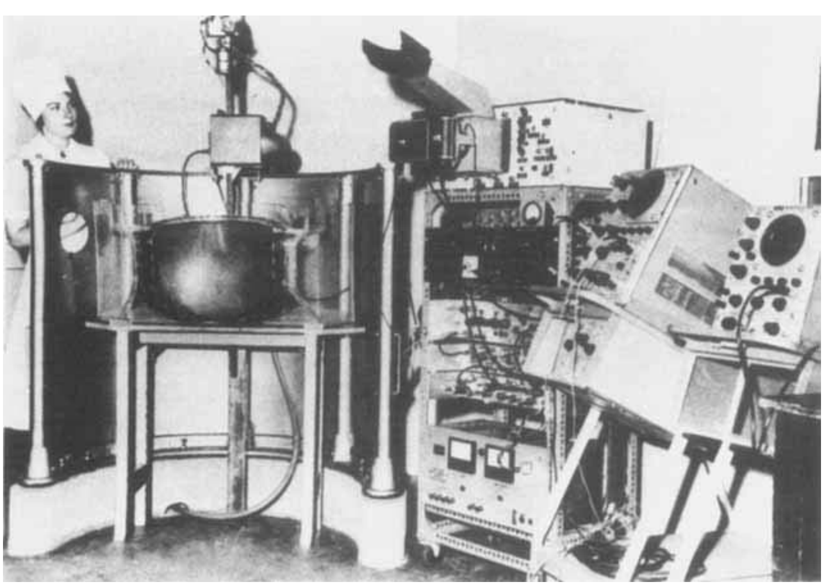

FIGURE 20. First water path contact-compound scanner built by the Ultrasonics Institute of Australia group, called Mark I. (Reproduced with permission from George Kossoff.)

development of diagnostic ultrasound during the first decade of A.I.U.M. Studies in the fields where ultrasound currently contributes the most—namely, echocardiography, ophthalmology, obstetrics and gynecology, and the abdomen—had all been initiated at that time. Some of the early steps were quite definite, and in several specialty areas they contributed significantly to immediate clinical use of ultrasound diagnostically. However, very few physicians in other specialties were willing to accept the clinical applications of ultrasound or to foresee to what extent ultrasound would contribute to future diagnostic applications in medicine.

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