Chapter 1
History of Ultrasound

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Ultrasound is the portion of the acoustic spectrum characterized by sonic waves that emanate at frequencies greater than that of the upper limit of sound audible to humans, 20 kHz. A phenomenon of physics that is found throughout nature, ultrasound is utilized by rodents, dogs, moths, dolphins, whales, frogs, and bats for a variety of purposes, including communication, evading predators, and locating prey [1–4]. Lorenzo Spallazani, an eighteenth century Italian biologist and physiologist, was the first to provide experimental evidence that nonaudible sound exists. Moreover, he hypothesized the utility of ultrasound in his work with bats by demonstrating that bats use sound rather than sight to locate insects and avoid obstacles during flight; this was proven in an experiment where blind-folded bats were able to fly without navigational difficulty while bats with their mouths covered were not. He later determined through operant conditioning that the *Eptesicus fuscus* bat can perceive tones between 2.5 and 100 kHz [5, 6].

The human application of ultrasound began in 1880 with the work of brothers Pierre and Jacques Curie, who discovered that when pressure is applied to certain crystals, they generate electric voltage [7]. The following year, Gabriel Lippmann demonstrated the reciprocal effect, that crystals placed in an electric field become compressed [8]. The Curies demonstrated that when placed in an alternating electric current, the crystals either underwent expansion or contraction, and produced high frequency sound waves, thus creating the foundation for further work on piezoelectricity. Pierre Curie met his future wife, Marie—with whom he later shared the Nobel Prize for their work on radioactivity [9]—in 1894, when Marie was searching

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for a way to measure the radioactive emission of uranium salts. She turned to the piezoelectric quartz crystal as a solution, combining it with an ionization chamber and quadrant electrometer marking the first time piezoelectricity was used as an investigative tool [10].

Ultrasound was not used as a diagnostic modality in human tissue until 1936, when German scientist Raimar Pohlman described a converter capable of taking acoustic waves and displaying this “acoustic image” as a visual entity. In 1940, Austrian neurologist Karl Dussik attempted to map the human brain and locate brain tumors using partially immersed transducers that were placed on each side of a patient’s head. At a frequency of 1.2 MHz, Dussik’s “hyperphonography” was able to produce low resolution “ventriculograms” [11].

In 1949, John Wild, a surgeon who had spent time in World War II treating numerous soldiers with abdominal distention following explosions, used military aviation-grade ultrasonic equipment to measure bowel thickness as a noninvasive tool to determine the need for surgical intervention. He later used A-mode, or amplitude-mode, comparisons of normal and cancerous tissue to demonstrate that ultrasound could be useful in the detection of cancer growth. Wild teamed up with engineer John Reid to build the first portable “echograph” for use in hospitals and also to develop a scanner that was capable of detecting breast and colon cancer by using pulsed waves to allow display the location and reflectivity of an object, a mode that would later be described as “brightness mode” or simply B-mode [12–14].

The use of ultrasound in obstetrics and gynecology began in 1954 when Ian Donald became interested in the use of A-mode, which uses a single transducer to plot echoes on a screen as a function of depth; one of the early uses of this was to differentiate solid from cystic masses. Using a borrowed flaw-detector, he initially found that the patterns of the two masses were sonically unique. Working with the research department of an atomic boilermaker company, he led a team that developed the first contact scanner. Obviating the need for a large water bath, this device was hand-operated and kept in contact with skin and coupled with olive oil. Captured on Polaroid film with an open shutter, abdominal masses could be reliably and reproducibly differentiated using ultrasound. Three years later, Donald collaborated with his team of engineers to develop a means to measure distances on the output on a cathode ray tube, which was subsequently used to determine fetal head size [12, 15, 16].

History of Doppler Ultrasound

In 1842, Christian Johann Doppler theorized that the frequency of light received at a distance from a fixed source is different than the frequency emitted if the source is in motion [17]. More than 100 years later, this principle was applied to sound by Satomura in his study on cardiac valvular motion and peripheral blood vessel pulsation [18]. In 1958, Seattle pediatrician Rushmer and his team of engineers further advanced the technology with their development of transcutaneous continuous-wave flow measurements and spectral analysis in peripheral and extracranial brain vessels [19]. Real-time imaging—developed in 1962 by Homes—was born out of the principal of "compounding," which allowed the sonographer to sweep the transducer across the target to continuously add information to the scan; the phosphor decay display left residual images from the prior transducer position on the screen, allowing the entire target to be visualized [12]. The first commercially available real-time scanner was produced by Siemens, and its first published use was in the diagnosis of hydrops fetalis [20, 21].

The addition of color flow mapping to Doppler ultrasound allowed real-time mapping of blood flow patterns [22]. The limitations of color flow, including angle-dependence and difficulty assessing flow in slow-flow states, were soon appreciated. These were overcome with the advent of an alternative form of Doppler, termed "Power Doppler." This alternative to routine color flow was found to be useful in confirming or excluding difficult cases of testicular or ovarian torsion and vascular thrombosis [23]. All of the preceding developments set the stage for the use of ultrasound in the diagnosis of penile and scrotal pathology.

History of Penile Ultrasound

The earliest reports on the use of ultrasound of the penis were for the diagnoses of Peyronie's disease and for impotence in 1971 and 1973, respectively. Malvar, Baron, and Clark used Doppler ultrasound to study penile blood flow in 36 patients. The three main penile arteries were studied, and a scoring system was devised where each artery was scored 0–3, where 0 was "no flow," 1 was a "low pitched dull sound with small elevation on the recorder," 2 was a "high pitched single sound with intermediate deflection," and 3 points were given when the "flow sounds and signals approximated that of the radial artery." Potent patients demonstrated an average score of 5.6 while impotent patients had an average score of 4.6. The authors conclude that ultrasound was sufficient to diagnose patients with penile arterial insufficiency [24] (Fig. 1).

Engel, Burnham, and Carter took this principle one step further and compared penile blood pressure to brachial blood pressure, using Doppler signal to confirm direction of arterial flow. They found a significant difference in penile-brachial index between impotent and normal patients, and concluded that ultrasound and blood pressure could be used as additional objective criteria to segregate organic from psychogenic impotence [25]. Velcek et al. further elucidated the concept of penile vascular insufficiency with their concept of penile-radial flow index. In this study, they compared arterial acceleration—defined as peak velocity over pulse rise time—between the penile arteries (averaged) and the radial artery. They found that impotent men had a flow index of 21.7 compared with normal men who had a flow index of 3.4. Penile vascular compromise was thus reflected by a decreased peak velocity, or prolonged pulse rise time with blunted velocity [26].

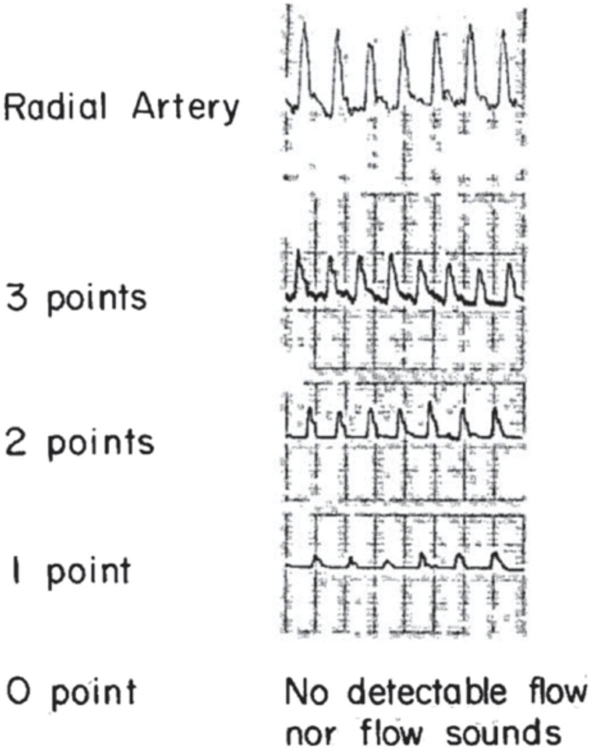

Fig. 1 Penile blood flow scoring system devised by Malvar et al. [24]. Each artery was evaluated. 0 points were given for "no flow," 1 point for a "low pitched dull sound with small elevation on the recorder," 2 points for a "high pitched single sound with intermediate deflection," and 3 points when the "flow sounds and signals approximated that of the radial artery"

In 1981, multiple investigators sought to better evaluate patients with Peyronie's disease using ultrasound imaging. Altaffer and Jordan at the Naval Regional Medical Center, and Fleischer and Rhamy at Vanderbilt simultaneously published case reports totaling three patients where ultrasound was used to visualize echogenic lesions with posterior shadowing between Buck's fascia and the tunica albuginea [27, 28]. Areas of normal penile shaft were easily discerned from areas affected by Peyronie's disease, and noncalcified plaques could be discerned from calcified plaques based on the absence or presence of posterior shadowing. The authors of each study concluded that sonography can be used to better evaluate patients for potential medical therapy. The same year, Gelbard et al. reported a case series of 13 patients with Peyronie's disease who were evaluated with ultrasound. In this study, they devised a complex penile water bath to remove the air interface, which resulted in a clearer resolution picture. Based on this study, they reported that precise measurement of plaques may not be necessary, but can be useful in tracking patients who undergo treatment for Peyronie's disease [29] (Fig. 2).

Dierks and Hawkins used penile ultrasound in 1983 to assist with their management of penile fracture. In this case report, a 26-year-old male experienced a traumatic bending of his erect penis, resulting in a "pop" sound followed by rapid detumescence and swelling. After an initial course of failed observation, ultrasound was performed and a large hematoma was seen as an echolucent mass with internal

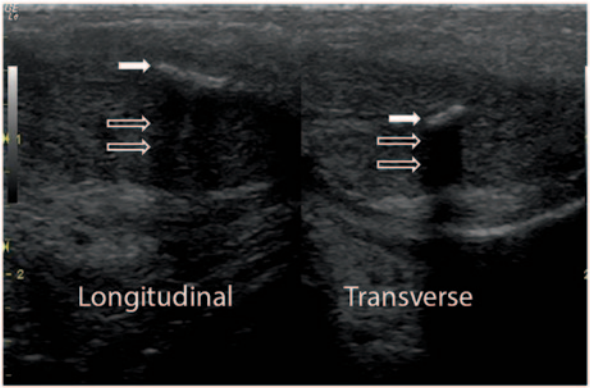

Fig. 2 Ultrasound of Peyronie's plaque. An echodense plaque (*solid arrows*) is imaged both in the longitudinal and transverse projection. Note the posterior shadowing suggestive of a calcified plaque (*open arrows*)

echoes and average through transmission. No definite tears were seen, but the patient was taken to the operating room (OR) for exploration, where the hematoma was evacuated and a small tunica alubinea tear was found. The authors made four recommendations based on this case to be applied to any case of penile trauma: (1) The entire tunica albuginea should be imaged to evaluate for tears, including proximally, (2) The entire corpora should be imaged for breaks or cystic collections, (3) The urethra and spongiosum should be imaged, and (4) Dimensions of the hematoma should be described [30].

History of Scrotal Ultrasound

One of the earliest uses of ultrasound for the scrotum was for the diagnosis of testicular torsion. In 1976, Perri et al. attempted to improve upon the contemporary overall testicular salvage rate of 25–37 % in cases of torsion with the use of their "Doppler stethoscope." In this study, an ultrasound device that emitted Doppler signal was scanned over the scrotum, while the operator listened to the received signal with the attached stethoscope. This was done on 30 patients who presented with scrotal pain: 23 were diagnosed with epididymo-orchitis, as determined clinically and by increased blood flow on Doppler; the remaining 7 were explored, of which 3 had torsion and 4 had torsed appendix testes. The authors concluded that Doppler has an important role in the differentiation between infectious and vascular etiologies, and that in the future it will have a role in differentiating torsed spermatic cord from appendix testis. Moreover, in the three cases of true testicular torsion, two were salvaged and this was confirmed intraoperatively by Doppler. The single case where orchiectomy was performed was presumed to be an in utero torsion [31].

Scrotal trauma was evaluated for the first time with ultrasound in the early 1980s. Albert reported three cases of direct scrotal trauma where ultrasound demonstrated increased echoes within the tunica albuginea, suggestive of hematoma and tunica disruption. All three cases were confirmed on exploration, with hematoma evacuation and primary repair of the tunica performed in two cases, and orchiectomy in one case where the testis was no longer viable presumably due to delay in presentation. The author reported that ultrasound was fast and easy to interpret in the diagnosis of scrotal trauma, given that normal testicles are homogeneous in echotexture while hematomas appear as areas of dense, heterogeneous echoes [32].

The first case series reporting the use of ultrasound in the diagnosis of varicoceles in men presenting with subfertility came in 1977 out of the University of Pennsylvania. In this study, Greenburg et al. examined 46 men, divided into a group of patients with varicoceles found on physical examination, oligospermic men with no palpable varicocele, and patients who were status post-varicocele ligation. All men had “Doppler stethoscope” examinations performed. All patients with clinically obvious varicoceles had Doppler exams that confirmed these findings; large varicoceles were found to demonstrate continuous non-pulsatile “hums” as the patient breathed quietly, and regurgitant flow as the patient performed a Valsalva maneuver. Of the group with oligospermia but no clinically palpable varicocele, Doppler found patterns similar to those of the first group in 5 out of 13 patients. All five patients had sperm densities similar to the first group, whereas all of the remaining eight patients had sperm densities within normal limits. Finally, in the group of five patients who were status post varicocelectomy, three demonstrated normal semen parameters, and concordantly, had normal sonographic findings. The remaining two patients had persistent abnormalities in their semen analysis, along with flow patterns reflective of persistent varicoceles [33].

The use of ultrasound for the diagnosis of scrotal masses was also explored in 1977, when three institutions reported their case series along with detailed sonographic findings. Kohiri et al. reported findings of 18 patients with scrotal masses, including 7 hydroceles, 3 tumors, 3 cases of epididymo-orchitis, 2 torsed testicles, and 1 traumatic injury [34]. Ultrasound correctly diagnosed 16 out of 18, failing to correctly diagnose both cases of torsion (Fig. 3).

The same year, Shawker reported his series of 14 patients with scrotal masses palpated on exam. Ultrasound correctly diagnosed 11 hydroceles, one case of epididymitis with reactive hydrocele, one indirect inguinal hernia, and one hematocele [35]. Finally, Gottesman et al. described the combined series from University of California, Los Angeles (UCLA) and Rush, which included 27 patients, of which 20 were referred for palpable scrotal mass, 4 for pain, and 3 for a finding of enlarged retroperitoneal lymph nodes. Of the 54 testicles assessed in the study, 25 were normal, and Ultrasound was able to correctly diagnose 27 of the remaining 29 abnormalities. In all, 21 sonograms demonstrated extratesticular lesions, while the remaining 6 were testicular tumors. The two indeterminate cases were a hemorrhagic hydrocele and a large sarcoma [36]. Each series, along with a review article by Miskin et al. described similar sonographic findings in each type of scrotal pathology: (1) Hydroceles appear as a normal testis surrounded by sonolucent fluid, (2) Masses demonstrate normal echogenicity in a portion of the testicle, while the space occupied by the mass demonstrates a cluster of internal echoes, (3) Epididymitis appears as clustered echoes separate from the testicle itself, (4) Hernias demonstrate

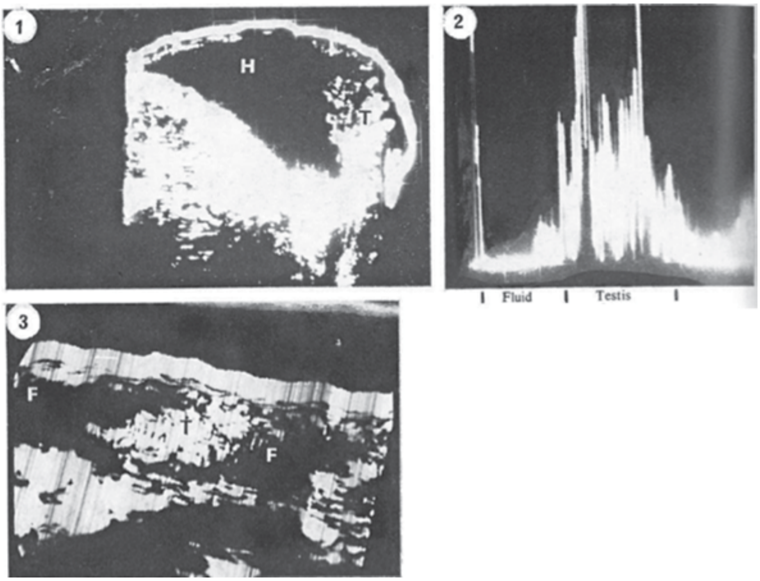

Fig. 3 Three ultrasound scans of testis and hydrocele [34]. Case 1: Longitudinal B-scan shows the clear echo-free large hydrocele (*H*) lying anterior to a testicle (*T*). Case 2: A-scan demonstrated that there are no internal echoes. On B-scan, the pattern was almost similar to case 1. Case 3: The testis (*T*) is surrounded by fluid (*F*). At surgery the cryptorchidism with hydrocele and varicocele was found

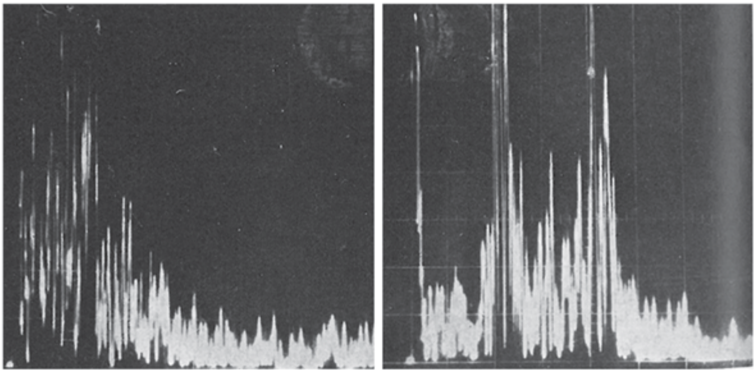

Fig. 4 A-scan ultrasound of normal testis (*left*) vs neoplasm (*right*) [34]

a lack of posterior wall echoes, indicating the presence of gas, (5) Abscesses show areas of lucency intermixed with areas of increased echoes within the testicle, (6) Varicoceles demonstrate clustered echoes with non-pulsatile waveform on Doppler, and (7) Spermatoceles appear as sonolucent cystic masses at the upper pole of the testicle [34–37] (Fig. 4).

Conclusion

The history of ultrasound is quite extensive and has involved a number of groundbreaking discoveries and new applications of basic physical principles. These findings have ultimately led to the routine use of ultrasound in the Urologist's office in the diagnosis of penile and scrotal pathology. As technology has evolved and ultrasound has become more reliable, it has slowly gained acceptance as an extension of the physical examination of a patient. Although this chapter was intended to serve as homage to the innovators of the past, it also serves to acknowledge that future work in the development of new applications for ultrasound will always be needed.

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