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Practical Urological Ultrasound

Humana Press

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Practical Urological Ultrasound

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To Martin I. Resnick, MD (1943–2007) whose innovation and leadership are an enduring inspiration.

Foreword

Hark! Sound belongs to the masses! Similarly, ultrasound is not the private domain of the designated "imagers" in medicine but belongs to all members of the healing arts to the extent they wish to learn and employ it. Sound is the great equalizer providing a measure of social equality within medicine that unlike its royal sisters of imaging (i.e., fluoroscopic, computed tomographic, or magnetic resonance) is available equally and inexpensively (portable units are now <$50,000) to all.

As with endoscopy, urologists have the opportunity to be leaders in this field, and within the chapters of this book are the tickets for admission. Within these 14 chapters, all aspects of ultrasonographic urology are addressed. Drs. Pat Fulgham and Bruce Gilbert have graced us with a "labor of love," three years in the making; such is their belief, which I share, that ultrasound is the future of urology and needs to be accepted as an essential part of the urologist's training and practice. This is "opportunity come knocking".

The organs of our specialty are largely hidden from "view"—ultrasound makes them all visible, uncloaking the future and empowering physicians to favorably alter time's course on behalf of each patient. Will more renal, testicular, and possibly bladder tumors be "discovered?" Absolutely. Will their early discovery and treatment lead to a state much like we have seen with PSA and prostate cancer, in which the incidence of metastatic disease dramatically decreases and the longevity curve for each cancer is Turned "upward?" Only carefully done studies will tell, but already this technology is proving its worth as now follow-up studies for renal stones can be done with the ultrasound unit in the office, thereby saving the patient the time, money, and X-ray exposure of numerous "low-dose" CT scans.

I urge each urologic surgeon to embrace this technology in the fullest sense of its potential, for it is the ticket to a new realm of medicine, one in which we predict and thus prevent the disease before it occurs, proactively diagnose an impending illness prior to the development of debilitating symptoms, and treat/cure a malady in the most minimalist fashion, for the earlier

the diagnosis, the less the cost in dollars and human suffering for the cure. With apologies, here be at long last a non-Macbethian future in which:

> Life's defined in a passing shadow, a skilled imager
> Who scans and sets this 10 minutes upon the stage.
> And then recorded evermore.
> It is a tale.
> Told by a transducer, full of sound—not fury,
> Signifying everything.

August 9, 2012 Ralph V. Clayman

Preface

The genesis of this book was the conflicted conviction that ultrasound has a critical role to play in the management of urologic patients but that it would never be considered an integral part of the specialty of urology until there was a body of scholarly literature on the subject generated by urologists.

Urologists had been performing and interpreting transrectal ultrasound of the prostate for many years and routinely interpreting ultrasound examinations of the kidneys, bladder, and male genitalia, but comparatively few urologists were both performing and interpreting all of these studies on their patients. Therefore, the necessary preamble to this work was the identification of a group of urologists who were clinical experts in all aspects of urologic ultrasound. This group, the American Urological Association's (AUA) National Urologic Ultrasound Faculty, founded in 2007, began the ambitious project of educating themselves about the fundamentals of ultrasound physics, the biologic effects of ultrasound, patient safety, and scanning technique.

A standard curriculum was developed to transmit this enhanced information about ultrasound to practicing urologists, many of whom had already been performing transrectal ultrasound for two decades. The American Urological Association Office of Education has offered this curriculum, including hands-on training, to thousands of urologists in the United States and around the world.

The anticipated and hoped for consequence of clinicians acquiring a thorough understanding of ultrasound technology and technique was the rapid extension of ultrasound to new applications and clinical procedures. This has come to pass. As a consequence, there has been a heightened interest in establishing accepted indications for imaging procedures and guidelines for performing high-quality studies. With the guidance of the AUA, the American Institute of Ultrasound of Medicine (AIUM) has established *Practice Guidelines for the Performance of Ultrasound in the Practice of Urology*™ published in 2012. The AIUM now offers, for the first time, practice accreditation for urologic ultrasound.

Urologists have now begun to publish original research on the basic science of ultrasound as well as many clinical studies. Ultrasound education has become a more formal component of residency training in urology.

With these foundational pieces in place, we felt it was time to bring the information together in a single work conceived and written exclusively by clinical urologists. As such, we hope the information will be both authoritative and practical.

Dallas, TX, USA Pat F. Fulgham, MD, FACS

Preface

Imaging in medicine has been, and will likely remain, the primary modality for identification of altered structure due to disease processes. As a noninvasive, safe, and relatively inexpensive imaging modality, ultrasound has been embraced by many medical specialties as the "go to" technology.

With ever-changing technology and regulatory requirements, this book was envisaged to provide a compendium of information for the practicing urologist, beginning with the physical science of ultrasound and continuing through clinical applications in urology. It is our hope that this will be the first of many literary endeavors of urologists for urologists interested in performing and interpreting urologic ultrasound studies.

Ultrasound has often been referred to as the urologist's stethoscope because much of the genitourinary system is not easily evaluated by physical examination and requires imaging for diagnosis. Therein lies one of the unique aspects of ultrasound studies performed and interpreted by urologists. The mandate to examine the patient coupled with the urologist's experience in both surgical and medical treatment engenders an unparalleled ability to meld the healer's art with advanced imaging technology. It is our fervent hope that this text might encourage more urologists to embrace the art and science of ultrasound in their mission to provide excellence in patient care.

New Hyde Park, NY, USA — Bruce R. Gilbert, MD, PhD, FACS

Acknowledgements

Pat F. Fulgham MD, FACS

This book would not have been possible without the dedication and expertise of our contributing authors, many of whom are leading the way in research and developing new applications in urologic ultrasound.

Dr. Claus Roerhborn brought the practice of office-based ultrasound with him from Germany in 1983. Dr. Marty Resnick enlisted Claus to help educate a generation of urologists. They developed the early AUA Office of Education courses on urologic ultrasound which became the basis for much of the material in this book.

Special thanks to Dr. Bruce Gilbert whose knowledge and patience were the perfect modulating qualities for helping bind the complex pieces together into a cohesive "whole." His passion for teaching is infectious.

Angela Clark provided invaluable assistance in manuscript preparation, image preparation and labeling, graphics production, and research. Her talented project management, including dogged pursuit of the "finished product," has been the glue holding the project together.

Finally, thanks to my family whose forbearance permitted me the many distracted hours of writing and editing necessary to complete what proved to be a multiyear journey. It was a "task" in one sense but also a joy to see urologists take ownership of ultrasound as an invaluable tool in the management of their patients.

Bruce R. Gilbert MD, PhD, FACS

This book was the vision of my coeditor, colleague, and friend Dr. Pat Fulgham. Through his leadership over this past decade, he has helped elevate the art of urologic ultrasound to a subspecialty within urology. He is a gifted surgeon, articulate spokesman, and tireless academician who accepts nothing less than perfection from himself, which is Contagious amongst all who have had the great fortune to work with him.

To the authors of this book, I am indebted. They have tirelessly given of their precious time away from family and their busy clinical practices to share their experience. Their teachings as expressed in this text form the basis of urologic ultrasound.

My wife, and best friend Betsy, has been the most supportive and loving partner through the late nights and endless weekends involved in this project. She is, and has always been, my source of inspiration.

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History of Ultrasound in Urology

1

Nikhil Waingankar and Bruce R. Gilbert

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 non-audible 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 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; this marked the first time piezoelectricity was used as an investigative tool [10].

The sinking of the RMS Titanic in 1912 drove the public's desire for a device capable of echolocation, or the use of sound waves to locate hidden objects. This was intensified 2 years later with the beginning of World War I, as submarine warfare became a vital part of both the Central and Allied Powers' strategies. Canadian inventor Reginald Aubrey Fessenden—perhaps most famous for his work in pioneering radio broadcasting and developing the Niagara Falls power plant—volunteered during World War I to help create an acoustic-based system for echolocation. Within 3 months he developed a high-power oscillator consisting of a 20 cm copper tube placed in a pattern of perpendicularly oriented magnetic fields that was capable of detecting an iceberg 2 miles away and being detected underwater by a receiver placed 50 miles away [11].

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A contemporary of Fessenden and student of Pierre Curie, Paul Langevin was similarly interested in using acoustic technology for the detection of submarines in World War I. Using piezoelectricity, he developed an ultrasound generator in which the frequency of the alternating field was matched to the resonant frequency of the quartz crystals. This resonance evoked by the crystal produced mechanical waves that were transmitted through the surrounding medium in ultrasonic frequency and were subsequently detected by the same crystals [12, 13]. Dubbed the "hydrophone," this represented the first model of what we know today as sound navigation and ranging, or SONAR. Although there were only sporadic reports on the use of SONAR in sinking German U-boats, SONAR was vital to both the Allied and Axis Powers during World War II [14].

In 1928, Russian scientist Sergei Sokolov further advanced the applicability of ultrasound in his experiments at Ulyanov Electrotechnical Institute. Using a "reflectoscope," Sokolov directed sound waves through metal objects, which were reflected at the opposite side of the object and traveled back to the reflectoscope. He determined that flaws within the metals would alter the otherwise predictable course of the sound waves. Sokolov also proposed the first "sonic camera," in which a metal's flaw could be imaged in high resolution. The actual output, however, was not adequate for practical usage. These early experiments describe what we now know as through transmission [15]. Sokolov is regarded by many as the "Father of Ultrasonics" and was awarded the Stalin prize for his work [13].

In 1936, German scientist Raimar Pohlman described an ultrasonic imaging method based on transmission via acoustic lenses, with conversion of the acoustic image into a visual entity. Two years later, Pohlman became the first to describe the use of ultrasound as a treatment modality when he observed its therapeutic effect when introduced into human tissues [16]. Austrian neurologist Karl Dussik is credited with being the first to use ultrasound as a diagnostic tool. In 1940 in a series of experiments attempting to map the human brain and potentially locate brain tumors, transducers were placed on each side of a patient's head, which along with the transducers was partially immersed in water. At a frequency of 1.2 MHz, Dussik's "hyperphonography" was able to produce low-resolution "ventriculograms" [17]. Other investigators were unable to reproduce the same images as Dussik, sparking controversy that his may have not been true images of the cerebral ventricles, but rather, acoustic artifact. Dussik's work led MIT physician HT Ballantyne to conduct similar experiments, where they demonstrated that an empty skull produces the same images obtained by Dussik. They concluded that attenuation patterns produced by the skull were contributing to the patterns that Dussik had previously thought resulted from changes in acoustic transmission caused by the ventricles. These findings led the United States Atomic Energy Commission to conclude that ultrasound had no role in the diagnosis of brain pathology [18, 19].

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 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 of the location and reflectivity of an object, a mode that would later be described as "brightness mode," or simply B-mode [13, 20, 21].

Following the post-World War II resurgence of interest in cardiac surgery, Inge Edler and Hellmuth Hertz began to investigate noninvasive methods of detecting mitral stenosis, a disease with relatively poor results at the time. Using an ultrasonic reflectoscope with tracings recorded on slowly moving photographic film designed by Hertz, they were able to capture moving structures within the heart. Dubbed "ultrasound cardiography," this represented the first echocardiogram, which was capable of differentiating mitral stenosis from mitral regurgitation and detecting atrial thrombi, myxomas, and pericardial effusions [22, 23] (Fig. 1.1).

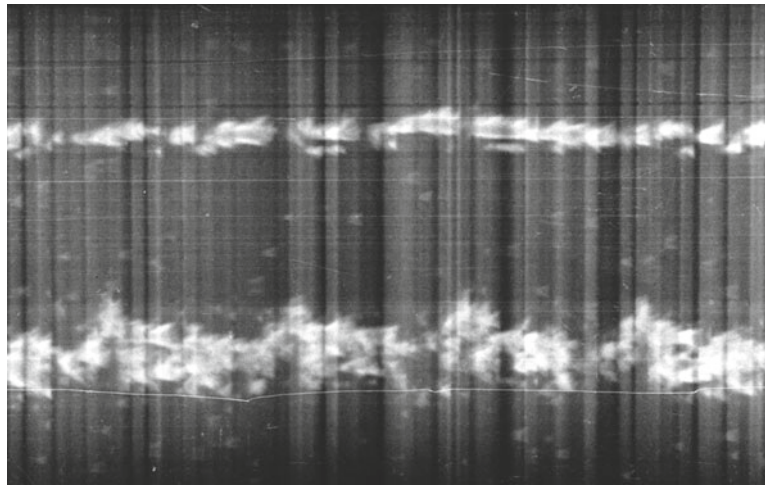

Fig. 1.1 First "motion-mode," or M-mode, tracing displaying ultrasonic tracings of moving cardiac structures. From [23]

With the support of the Veterans Administration and United States Public Health Service, Holmes et al. described the use of ultrasound to detect soft tissue structures with an ultrasonic "sonascope." This consisted of a large water bath in which the patient would sit, a sound generator mounted on the tub, and an oscilloscope which would display the images. The sonascope was capable of identifying a cirrhotic liver, renal cyst, and differentiating veins, arteries, and nerves in the neck. Consistent with the results of their predecessors, however, they were unable to produce meaningful ultrasound images of the brain [24].

The use of ultrasound in obstetrics and gynecology began in 1954 when Ian Donald became interested in the use of A-mode, or amplitude-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 [13, 25, 26].

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 [27]. 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 [28]. 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 [29]. Real-time imaging—developed in 1962 by Holmes—was born out of the principle 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 [13]. The first commercially available real-time scanner was

produced by Siemens, and its first published use was in the diagnosis of hydrops fetalis [30, 31].

Bernstine and Callagan were the first to report the obstetric utility of Doppler in their 1964 report on ultrasonic detection of fetal heart movement, thus laying the foundation for continuous fetal monitoring [32]. The same year, Buschmann was the first to report "carotid echography" for the diagnosis of carotid artery thrombosis [33], although debate ensued as to whether ultrasound was capable of identifying the carotid bifurcation or its branches into the internal and external carotid arteries [34–37].

In 1966, Kato and Izumi developed directional Doppler that was capable of determining direction of flow [31, 38]. The following year, McLeod in the United States reported similar findings using phase shift in the United States [31, 39]. By 1967, the use of Doppler ultrasound had spread to Europe, where continuous-wave ultrasound (which does not allow precise spatial localization) was being used to diagnose occlusive disease of neck and limb arteries, venous thrombosis, and valvular insufficiency with accuracy [40]. Pulsed Doppler soon provided the capability of sampling specific Doppler signals in target tissues, a function that quickly became clinically applicable in the detection of valvular motion and differential flow rates within the heart [41].

The addition of color flow mapping to Doppler ultrasound allowed real-time mapping of blood flow patterns [42]. 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 [43].

In 1989, Baba and colleagues reported on the first production of a three-dimensional ultrasonic image. Using a real-time straight or curved transducer, they were able to obtain positional information with an ultrasound device that was connected to a microcomputer, which reconstructed the data into a three-dimensional output. The authors hypothesized that this system would be ideal for the screening of fetal anomalies and abnormalities in intrauterine growth [43]. Following the development of von Ramm's three-dimensional ultrasound device, Sheikh et al. published the first use of real-time three-dimensional acquisition and presentation of data in the United States in 1991. This proved to be useful in cardiology for assessment of perfusion and ventricular function [44].

History of Ultrasound in Urology

Prostate

In 1963, Japanese urologists Takahashi and Ouchi became the first to attempt ultrasonic examination of the prostate. However, the image quality that resulted was not interpretable and thus carried little medical utility [45]. Wild and Reid also attempted transrectal ultrasound, but were met with the same result. Progress was not made until Watanabe et al. demonstrated radial scanning that could adequately identify prostate and bladder pathology. Using a purpose-built device modeled after a museum sculpture entitled "Magician's Chair," Watanabe seated his patients on a chair with a hole cut in the center such that the transducer tube could be passed through the hole and into the rectum of the seated patient [46]. Images from Watanabe's seated probe are displayed below; it is evident in Fig. 1.2b (demonstrating an area of circumscribed symmetric echogenicity, representing BPH) and Fig. 1.2c (demonstrating an asymmetric area of hyperechogenicity, representing prostate cancer) that resolution was poor and images displayed extreme contrast. Subsequent development of biplane, high-frequency probes has created increased resolution and has allowed for transrectal ultrasound to become the standard for diagnosis of prostatic disease (Fig. 1.2a–c).

In 1974, Holm and Northeved introduced a transurethral ultrasonic device that would be interchangeable with conventional optics during cystoscopy for the purpose of imaging the prostate and bladder. Their goals for this device included the ability to determine the depth of bladder tumor penetration, prostatic volume, prostatic tumor progression, and to assist with transurethral resection of prostate [47].