Ultrasonography of the Prostate and Testes

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History

The first application of ultrasound in medical diagnosis occurred in 1942 when Karl Dussik placed transducers on patients’ craniums and recorded the through-transmission of the sound beam in an attempt to localize a brain tumor. In 1949, the first successful pulse echo system, which could record echoes from tissue interfaces, was developed by Douglas Howry and W. Roderic Bliss at the University of Colorado School of Medicine. In 1951, Wild and Neal of St Martin’s Hospital reported that A-mode display sonography was capable of showing differences between normal and abnormal tissues, and the following year, Wild and Reid published the first two-dimensional echograms of biological tissues (kidney cortex and myoblastoma of the thigh). In 1963, Takahashi and Ouchi were the first investigators to report the use of ultrasound to image the prostate via an abdominal approach, but, unfortunately, these A-mode display images were difficult to interpret and not clinically useful. A year later, these investigators successfully obtained tomographic pictures of the prostate with the use of a transrectal probe equipped with a radical scanning device. Although resolution improved, the images also were of poor quality and thought to be of no clinical value.

Watanabe and associates, using a chair device, are credited with obtaining the first clinically useful transrectal ultrasonographic images of the prostate in 1967 (Fig. 1). Remarkable improvement in ultrasonography of the prostate was obtained with the use of a transrectal radial probe with a special concave 3.5-MHz transducer covered with a water-filled balloon. A B-mode display was used, and reproducible transverse prostate images were visualized on a black-and-white screen. It is important to recognize that transrectal ultrasound scanning was also evaluated by VonMicsky, a gynecologist who developed an ultrasound scanning device in conjunction with a sigmoidoscope to visualize the pelvic structures.

The first reports of investigators in the United States using transrectal ultrasound for evaluation of the prostate came in 1972, and the images shown in the cathode ray tube (CRT) were recorded with a Polaroid camera (Fig. 2). These initial reports were the culmination of a number of experiments that were conducted beginning in 1968 at the Bowman Gray School of Medicine under the direction of William H. Boyce, who described these early developments. Initially studies were carried out with skin-coupled B-mode transducers through the perineum and other portals before the final decision was made to use an intrarectal balloon-coupled rotational array transducer.
It was mounted on a stable tripod, adjustable in height to the cystoscopic table and capable of fixation at virtually any angle selected by the operator as the planned position of reference (Fig. 3). The probe had a ratchet and a scale, which permitted the planned position to become 0 on the scale. The ratchet then moved the transducer a precise distance (1–5 mm) along the axis of the probe, permitting serial tomograms of the prostate and related structures. These “loaf-of-bread” slices permitted a three-dimensional reconstruction of the prostate gland (Fig. 4).

The first transducer was the 3.5-MHz generator receiver mounted at 90° from the long axis of the probe (Fig. 5). A single 360° sweep at a precise rate was made for each activation of an electronic motor, providing highly reproducible static sonograms. A plastic sheet protected the balloon from contact with the rotating element. The balloon covered the entire insertable probe and was filled with fluid through a tube in the probe shaft.

In 1968 and 1969, work progressed on construction of prototype equipment and attempts to solve the apparently simple problems of air

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**Figure 1.** Early chair device with a rectal probe for prostate imaging. Refinements in instrumentation simplified the examination, but all studies continued using the chair device.

**Figure 2.** Early transrectal equipment with a CRT and tripod device to position the probe. Early studies used fluoroscopy to document probe position and to correlate anatomic structures visualized with ultrasonographic images.

**Figure 3.** Patient in the lithotripsy position with the probe in place. The probe is mounted on a tripod with a planned position indicator.
bubbles, detection of highly absorptive inter-rectal interfaces, and establishment of reliable points of reference, both anatomic and ultrasonographic. More difficult problems included those of focusing, energy control, and permanent records from a CRT. It was learned that the air bubble problem could be eliminated by placing the patient in the knee-chest position. However, there was no electronic conversion capability, and it was essential to have a roadmap orientation of the sonogram to cystoscopic, fluoroscopic, radiologic, and physical examination of the patient. A great number of coupling agents and techniques were investigated, but none were satisfactory. Virtually everything done was repeated in all reasonable variations, modes, and patient positions.

In late 1969 and early 1970, the equipment was assembled in the Urology Department, and a protocol was developed for standardized examinations. Examinations were done on patients with well-defined urologic disease who required fluoroscopic examinations, radiographic examinations, or both, as well as cystoscopic evaluations. In addition to Dr William Boyce, Dr William King, Dr Mark Wilkiemeyer, and James Willard conducted these early investigations. Dr James Martin, Dr William McKinney, and Dr Fred Kremkau were also consultants lending their radiologic and ultrasonic experience to these early studies. In 1972, a scan converter and video screen with a capacity of 8 to 10 shades of gray were obtained, with considerable improvement in image quality (Fig. 6). For the 3 ensuing years from 1972 to 1975, many studies were carried out to assess urologic diseases of the pelvis. Thirty-five-millimeter filmstrips were used to record data, and the first clinical research program began in 1972, studying patients with localized carcinoma of the prostate. Recognition of advanced stages of prostate cancer was noted, but early stage disease could not be detected. Furthermore, it was noted that the locations of histologic cancer in radical prostatectomy specimens were often at variance with the sonographic impressions (Fig. 7).

In 1975, gray scale equipment with more than 18 shades of gray was acquired, and studies ensued addressing early diagnosis of prostate cancer, accurate staging of cancer of the bladder and prostate, and monitoring the response of prostate cancer to therapy. Much of this work was funded through the National Prostate
Cancer Project of the National Cancer Institute; I was the principal investigator. It was recognized that higher-frequency transducers were required, and with the assistance of Dr Ronald Heilman, higher-frequency transducers of up to 7 MHz were used. Gray scale quality was further enhanced by increasing the number of shades of gray produced by the scan converter, and the use of higher-frequency transducers improved the resolution of ultrasonographic imaging considerably (Figs. 8 and 9).

The introduction of electronic real-time imaging in the early 1980s further enhanced the quality of ultrasonographic images (Fig. 10). Shortly thereafter, the clinical applications of transrectal ultrasonography of the prostate began to expand, as evidenced by the dramatic increase in publications on transrectal ultrasonography of the prostate in the medical literature during the mid-1980s. Most investigators concluded that the transrectal techniques were preferable to transabdominal, transperineal, and transurethral techniques when visualizing the prostate because of more consistent and reproducible imaging. These alternative techniques oftentimes provided poor definition of the margins of the prostate depending on the approach and also were dependent on bladder distention to improve image quality. In recent times, other than for monitoring prostate size, transrectal techniques have been used uniformly. As further development of imaging processing occurs, it is likely that improvements in imaging quality will continue with the use of color and power Doppler imaging, development of ultrasonographic contrast agents, and improvement in three-dimensional imaging, which all promise to enhance the reliability and applicability of this examination.
Ultrasonographically Guided Biopsy

Ultrasonographically guided biopsy of the prostate has become a standard procedure in assessing patients with suspected carcinoma of the prostate based on the presence of abnormal digital rectal examination findings or elevation of the prostate-specific antigen level. The first investigators to use transrectal ultrasonographic guidance performed a biopsy via the transperineal route with the use of a radial scanner equipped with a special puncture attachment containing holes aligned parallel to the transducer (Fig. 11). Interestingly, Holm et al17 were the first to report the use of this technique for placement of radioactive “seeds” within the prostate for treating localized cancer of the prostate. This method of seed implantation continues today. Other investigators have used the longitudinal linear array transducer to perform the biopsy via the perineal route.18–20 As popularized by Lee and associates,21 more recently, transrectal ultrasonographic guidance has been used to perform transrectal biopsies and has become the standard in today’s practice.22–24 The procedure can be performed either freehand or with the use of a biopsy guide that is attached to the ultrasound probe. Transrectal techniques have multiple advantages over transperineal approaches in that the path of the needle is shorter, and deviation of the needle within the prostate is less likely to occur, thus making positioning easier. The procedure is quicker because there is no skin preparation, and local anesthesia, although not required, is being used with increasing frequency and has considerably reduced pain associated with the procedure. Although the risk of infection is greater with a transrectal approach, the use of prophylactic antibiotics has resulted in an infection rate of approximately 1%. Improvements in biopsy needles and the use of spring-loaded biopsy guns have improved prostate tissue samples and also have lessened patient discomfort.

Figure 8. Transrectal probe with 3.5- and 5.0-MHz transducers to enhance imaging of the prostate. Only 1 frequency was used at a time.

Figure 9. A, Scan of prostate with benign hyperplasia, 5.0-MHz transducer. B, Scan of prostate with benign hyperplasia, 3.5 MHz transducer.
The descriptions of prostate anatomy by Dr John McNeil also had a considerable impact on the technique of prostate biopsy. McNeil described the prostate as being composed of 3 glandular zones (peripheral, transition, and central) and the periurethral glands. The peripheral zone accounts for approximately 75% of glandular tissue of the normal prostate; however, with aging there is appreciable growth of the transition zone, which gives rise predominantly to benign prostatic hyperplasia. The peripheral zone is the most frequent site of origin of carcinoma. Initially McNeil’s concept of zonal anatomy had little utility in the clinical sphere or in diagnostic imaging; however, with the development of cross-sectional imaging techniques, the zonal concept of anatomy became useful because it not only permitted interpretation of sonographic images of the internal structure of the prostate but also assisted in guiding prostate biopsy. Many malignancies were recognized as occurring in specific areas, and although the association with hypoechoic areas within the peripheral zone was noted, it became increasingly apparent that many malignancies were isoechoic and were not visualized with standard ultrasonographic imaging techniques. It was Hodge and associates at Stanford University who introduced the concept of sextant biopsies of the prostate based on the increased understanding of prostate anatomy, which improved the detection of prostate cancer. It must also be recognized that Cooner et al also brought attention to the importance of zonal anatomy and interpretation of ultrasonographic images and recognized the potential value of prostate ultrasonography in the detection and diagnosis of early cancer of the prostate. Many studies that expanded on the observations of Hodge et al have ensued, and several investigators have shown the value of increasing the number of biopsies, particularly with sampling of the peripheral zone.

As noted previously, interstitial radiation therapy has been used with increasing frequency, and the techniques described by Holm and associates continue to be used today. Various imaging modalities are being developed to help localize prostate cancer within the gland so that seed implantation can be more specifically directed. This will likely be a major development in the future.

**Testicular Imaging**

It is of interest that imaging of the scrotum and its contents also paralleled the development of clinical applications of ultrasonography. Early experiences in the 1970s relied primarily on transducers of lower frequencies with limited gray scale capability, and textbooks during that time made only limited references to testicular imaging. In the late 1970s and early 1980s, the development of Doppler imaging, higher-frequency transducers, and offset devices allowed for better imaging of the scrotum and its contents. With these developments, various publications addressing this area of investigation began to appear.
Further developments in color and power Doppler studies not only allowed for the assessment of blood flow to the testes in the evaluation of patients with testicular torsion but also allowed for improved delineation of abnormalities within the testicle, which is very important in the assessment of patients with testicular masses and possible malignancy. Today, ultrasonography of the testes is a standard study in the assessment of patients with acute and chronic scrotal disorders and also in the evaluation of those with scrotal masses, which can include not only testicular malignancies but also hydroceles, varicoceles, spermatoceles, and other epididymal abnormalities. The technological developments have allowed these studies to become important components in patient evaluation.

References


