1 History of Interventional Urology

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> Urology can be said to owe its existence as a specialty to the inventive genius of Thomas Edison and Wilhelm Conrad. Reed Nesbit, 1956 [1]

Interventional urology owes its roots to the breathtaking work of some of the greatest minds of the last two centuries. Physicist, chemist, engineers, and physicians, either alone or as part of a team, have come, sometimes by accident, to the discovery of technologies that have been responsible for shaping the world of medicine to the continuously evolving science that it is today.

X-Rays

X-rays have been used to noninvasively probe the human body since their discovery in Germany by physics professor Wilhelm Conrad Röntgen, on 8 November 1895 [2]. It took only 6 weeks for him to complete his first scientific research on this phenomenon, and on December 28, that same year, he submitted it to Würzburg's Physical-Medical Society journal with the title "*On a New Kind of Ray: A Preliminary Communication*" [3]. Within a few weeks of Röntgen's announcement, the use of X-rays spread fast and widely, and its first reported use under clinical conditions was by John Hall-Edwards in Birmingham, England, on 11 January 1896, when he used them to locate a needle stuck in the hand of an associate [4].

In 1896, a total of 49 books and brochures, and 1,044 scientific essays were written on the scientific aspects and possible applications of the newly discovered X-rays. A multitude of these publications dealt specifically with possible applications in medicine [5].

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In the military, doctors started using X-rays to locate bullets in human flesh and photograph broken bones. X-rays were first used on casualties from the Abyssinian War of 1896, and the developing radiological technology rapidly progressed and was applied to military and general surgery [6] (Fig. 1.1).

X-Rays and Urology

Some of the earliest medical research involving X-rays involved the investigation and exposure of the biliary and renal tracts; John Macintyre, a Scottish doctor, imaged a kidney stone using X-rays. He was able to make a diagnosis of this stone only after five different patients suspected clinically of having renal calculus were photographed with negative results, but on the sixth attempt, in a patient previously known to have renal calculi, he was able to obtain a picture of an obliquely placed elongated deposit within the silhouette of the kidney. He confirmed the diagnosis in the subsequent operation and reported the case in the 11 July 1896 issue of *The Lancet* [8].

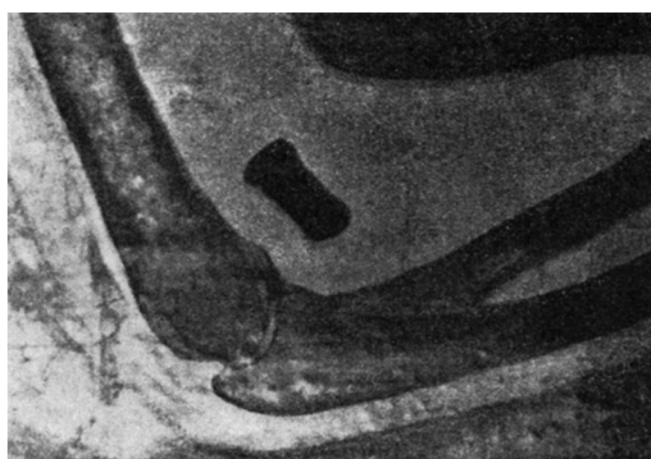

Fig. 1.1 A radiograph of a bullet in the elbow of a soldier 1897 (From Thomas [7] with permission)

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Before 1895, the practice of urology was almost exclusively based on cystoscopy, itself a relatively new development, as well as on laboratory and physical examination. Röntgen's discovery changed the world of urology forever. Dr. Henry W. Cattell, Instructor of Anatomy at the University of Pennsylvania, in the United States, wrote, "… the manifold uses to which Roentgen's discovery may be applied in medicine are so obvious that it is even now questionable whether a surgeon would be morally justified in performing a certain type of operations without first having seen pictured by this rays the field of his work…" [9].

Adding Contrast

The first documented contrast study of the urinary tract was performed in 1897 by the French surgeon Théodore Tuffier. He passed a radiopaque catheter through the ureteral orifice in the bladder hereby outlining the course of the ureter [10].

The first ureteral catheters in use were radiolucent and mounted around a lead wire; this technique was subsequently replaced by making the ureteral catheters themselves radiopaque, by impregnating their walls with iron oxide. In 1914, the urologist Pasteau invented a catheter, which included a semiopaque centimeter scale, to localize stones precisely [11].

The search for better ways to visualize the urinary tract continued; next came the use of air as a contrast agent by Wittek, who succeeded in demonstrating cystolithiasis, thus giving birth to the air cystogram [12].

Replacing air as a contrast medium was the next step, and Wulff, in 1904, was the first to employ a radiopaque solution composed of 10 % bismuth subnitrate and starch, filling what was in all likelihood a huge diverticulum as well as the bladder itself [13].

This solution was soon replaced by a different liquid contrast agent containing a colloidal suspension of silver, giving better image quality, and, by injecting larger quantities of solution into the bladder, delineating the ureters and renal pelvises, giving birth to the first retrograde pyelograms [14]. The usefulness of this technique was quickly recognized but, unfortunately, so were the dangers associated with the silver-containing contrast agent. The search for safer materials began, and sodium iodide solutions, first described by Cameron in 1918, [15] became the contrast agents of choice for retrograde pyelography.

The next step in this evolutionary process was to eliminate the need to directly introduce the contrast agent into the urinary system. An indirect means might be faster and safer. The discovery of iodine as intravenous safe radio contrast agent was accidental. In the early 1920s, when iodine-containing compounds were used to treat syphilis, a team of workers at the Mayo Clinic, Earl Osborne (a syphilologist), Albert Scholl (a urologist), Charles Sutherland (a radiologist), and Leonard Rowntree (an internist), described the use of intravenous and oral sodium iodide to visualize the urinary tract. Osborne noticed that the urinary bladder was visible on radiographs of patients taking large doses of oral and intravenous sodium iodide for the treatment of syphilis. The visualization of the renal pelvis was poor, but the authors calibrated the dose of iodine against the urinary iodine concentration and the degree of bladder radioopacity, and thus they went on to perform the first successful clinical pyelogram. However, sodium iodine was far too toxic for clinical radiodiagnosis [16].

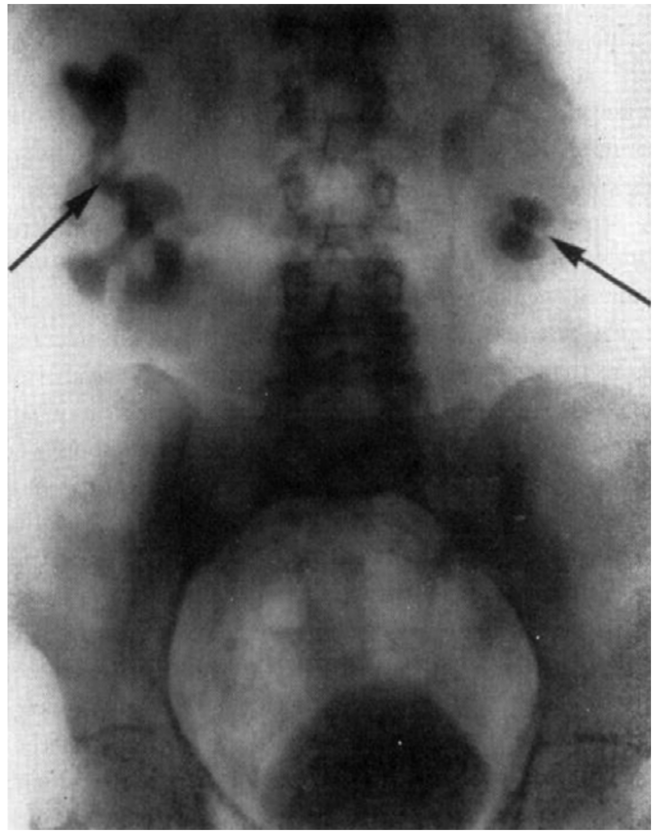

Fig. 1.2 Intravenous urography by Swick, (*arrows*) showing renal calyceal systems and bladder opacified (From Swick. [17] with permission)

A few years later, in 1928, Moses Swick, while an intern at Mount Sinai Hospital in the Department of Urology, traveled to Hamburg, Germany, on a research scholarship to work with Professor Leopold Lichtwitz in the treatment of human biliary infections with the use of iodinated drugs. It occurred to Swick that these drugs, containing iodine, might be of value in visualizing the renal tract by radiography [17]. He made several studies in laboratory animals. The initial studies were very encouraging, and, in order to gain access to the large number of patients, Swick transferred his work to Berlin to the urological department of Professor Alexander von Lichtenberg. Consequently, the first successful human intravenous urography (IVUs) was produced using a soluble iodinated pyridine compound solution (Uroselectan) [18–20] (Fig. 1.2).

In fact, iodinated pyridine compounds were routinely used to perform IV urography for the next 20 years.

Percutaneous Interventions

Percutaneous interventions on the urinary tract came much earlier than the discovery of X-rays. In 1686, Toler inserted cannulas through the perineum to relieve urinary retention from impassable urethral strictures.

Riolan used a suprapubic approach to the bladder, while Heisler, in 1770, left a suprapubic cannula in place permanently in men suffering from bladder outlet obstruction.

In the latter half of the tenth century, the Arab physician Serapion is said to have thrust a red-hot iron through the flank and extracted a renal calculus. A related story is the one of Hobson, British consul at Venice in the mid-seventeenth century, who, following surgery for renal colic, continued to pass urine through a fistula in his flank until one day his wife, using a small dagger for a probe, extracted a date-shaped calculus from the tract, after which the man had no more symptoms [21].

Thomas Hiller, a British pediatrician, in 1864, inserted a needle into the hydronephrotic kidney of a four-year-old boy and removed more than three liters of urine, repeating the procedure several times during the boy's life. [22] Several physicians took up this practice, but because of serious complications related to the procedure, especially peritonitis, caused it to be undertaken only under the most obliging circumstances, and it was eventually abandoned.

Interventional uroradiology as we know it today really began in 1939 when Archie Dean, an urologist at Memorial Hospital in New York, performed the first diagnostic percutaneous puncture of a renal mass. The return of clear fluid rather than blood made it possible to differentiate between cyst and neoplasms. However, in 1954, Wickbom, in Sweden [23], first utilized percutaneous puncture of the renal pelvis for antegrade pyelography and used this technique systematically in the diagnosis of outflow obstruction (Figs. 1.3 and 1.4).

A year later, Goodwin and Casey, from the University of California in Los Angeles, were the first to use percutaneous nephrostomy as a therapeutic approach for draining obstructed kidneys and gaining surgical access to the renal collecting system, leaving a length of polyethylene tubing for drainage [24].

Kurt Lindblom reported percutaneous puncture of both cystic and solid renal masses employing, for the first time, fluoroscopy for localization and contrast material instillation to outline the interior of the lesion [25].

The utility of upper urinary tract access was further expanded when Kapandji performed manometric studies of the renal pelvis following percutaneous puncture, serving as

Fig. 1.3 Antegrade pyelography (1954). After direct puncture of the left renal pelvis, contrast material demonstrates dilation of the pelvis and upper part of the ureter. There is complete obstruction of the ureter at the pelvic inlet (*arrow*) (From Wickbom. [23] with permission)

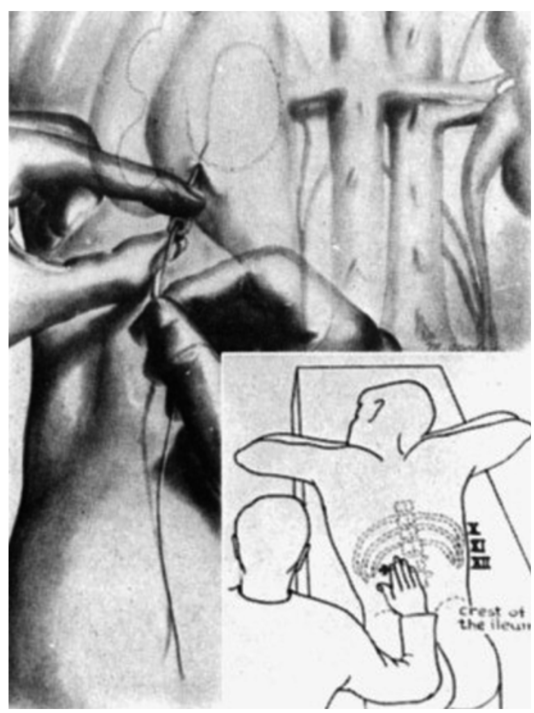

Fig. 1.4 Percutaneous trocar nephrostomy (1955): method and landmarks. Optimum puncture site is usually about five fingerbreadths lateral to midline and at a level where a 13th rib would be (From Wickbom. [23] with permission)

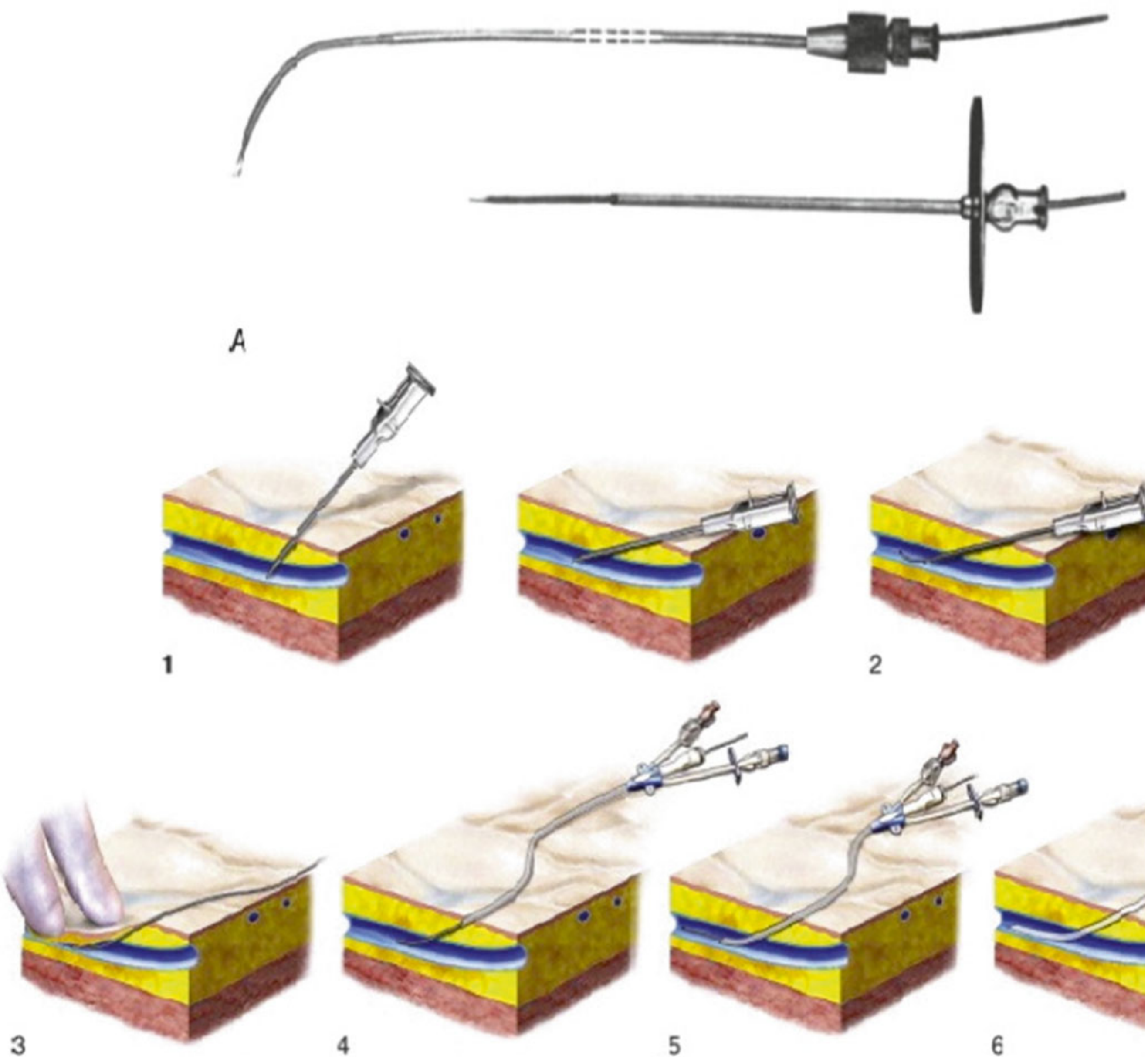

Fig. 1.5 Seldinger's technique (From Seldinger. [27] with permission). *1* Needle inserted into a vessel. *2* Wire guide inserted through the needle. 3. Needle comes out, leaving the wire guide in place 4–6 Catheter inserted over the wire and into the vessel

a base for the work of Robert Whitaker of Cambridge, England, who perfected the technique of pyeloureteral infusion with pressure-flow monitoring [26].

Goodwin and Casey's method was essentially blind, in order for them to insert a large trocar successfully, and it needed a markedly dilated renal collecting system. In 1965, Bartley and his associates in Göteborg in Sweden adapted Seldinger's method of vascular catheterization and implemented it in the placement of percutaneous nephrostomies (Fig. 1.5). They described the use of fluoroscopic localization, guide wires, and angiographic catheters, thereby giving rise to percutaneous nephrostomy (PCN) as it is similarly performed today [28].

In 1976, radiologist Ingmar Fernstrom and urologist Bengt Johansson published their benchmark work on removal of kidney and ureteral stones through a percutaneous approach and thus dramatically changed the practice of urology, giving birth to percutaneous nephrolithotomy (PCNL) [29].

Ultrasound

While at first renal biopsies were done "blindly," in 1956, Lusted and his associates introduced biopsy under fluoroscopic control. Subsequently, almost every imaging modality came to be utilized in localizing the kidney for biopsy [30].

Sonography-guided localization, which was first suggested by Berlyne in 1961, became the most popular method until this day [31].

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 [32].

In 1912, the sinking of the RMS Titanic sparked the public's desire for a device capable of echolocation. This was intensified 2 years later with the beginning of World War I, as submarine warfare became a vital part of war strategy. 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 two miles away and being detected underwater by a receiver placed 50 miles away [33].

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 [34].

A few years later, in 1954, Dr. Joseph Holmes, a nephrologist, 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 [35] (Fig. 1.6).

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. Progress was not made until in 1976 when Watanabe et al. demonstrated radial scanning that could adequately identify prostate and bladder pathology. 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 [36] (Fig. 1.7).

Astraldi, in 1925, was the first to carry out prostatic biopsies by the transrectal route. In 1930, Ferguson described a transperineal technique for aspirating prostatic tissue for cytological examination [37, 38]. Franzen first employed the currently used transrectal route for aspiration cytology in 1960.

The first to use real-time sonography for localizing the prostate for biopsy was done by Harada et al., while Ragde, Aldape, and Blasko adapted an automatic spring-loaded biopsy device (Biopty) for use in the prostate gland, making the procedure both more diagnostically accurate and less bothersome for patients [39–41].

Computed Tomography and Magnetic Resonance

Although the development of both CT and MRI technologies had almost a comparable timeline, each modality is based on a completely different principle. In 1917, Radon, a leading mathematician, found that formulas could be utilized to reconstruct a three-dimensional object from a very large number of two-dimensional projections of that object.

Based on Radon's principle and algorithms, in 1971, South African-born physicist Allan Cormack at Tufts University and English engineer Godfrey Hounsfield at EMI Laboratories in England, separately developed modern computer-based tomography scanning machines. In April 1972, at a seminar at the British Institute of Radiology, Hounsfield formally presented the results he had obtained using the EMI scanner, and descriptions of the device appeared in many publications, including The British Journal of Radiology.

Working independently, these two scientists later jointly received for their achievements the Nobel Prize for physiology or medicine in 1979.

In a very few months, by spring of 1974, computed tomography was recognized as a major improvement by radiologists throughout the world, and the name CT was soon known to politicians, government regulators, and the general public.

The first clinical CT scanners were installed between 1974 and 1976; they could only be used for the head and had a very slow scanning time of about 4.5 min for each image "slice." These were years of rapid growth in both use and media popularity of CT in neuroradiology practice. CT was not yet technically able to image other parts of the body with enough speed to be clinically useful [42–44].

Late in 1975, EMI, the original developer of the commercial CT scanner, announced a new CT unit, which successfully initiated a scanning technology with an eighteen-second scanning time that allowed practical imaging of the chest, abdomen, and pelvis. Body CT had arrived.

As advances in cross-sectional imaging allowed more expeditious acquisition of images, percutaneous biopsies started to be performed under CT guidance. The potent combination of accurate imaging with specific tissue diagnosis revolutionized the care of a wide range of patients and virtually ended the need for the exploratory laparotomy in specific cases [45, 46].

The drainage of intra-abdominal collections could be performed radiologically and percutaneously with

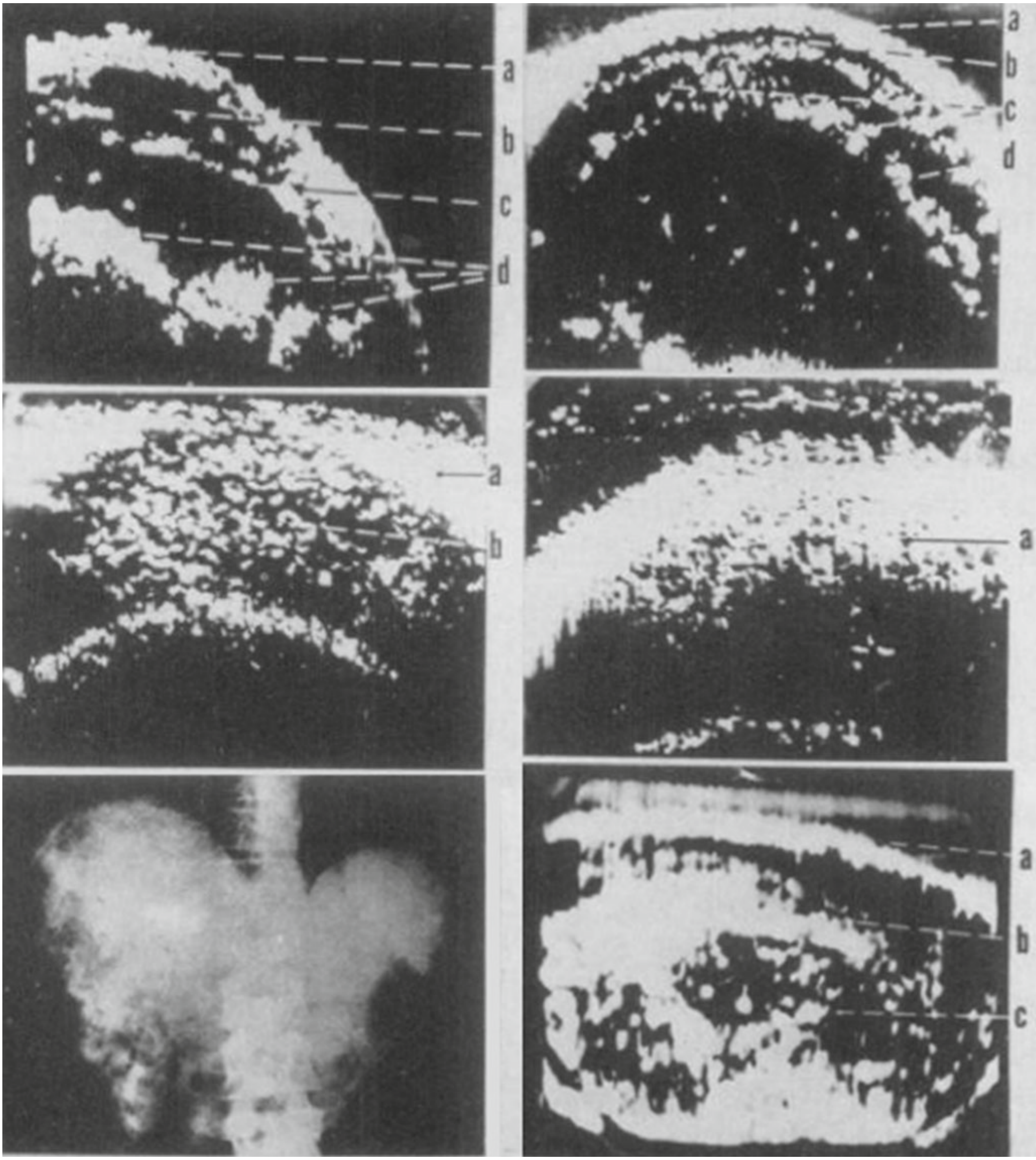

Fig. 1.6 Series of somagrams taken over the liver area of the abdomen. The first is of a normal individual as food is passing down the intestinal tract. (**a**) abdominal wall, (**b**, **c**) intestinal tract, (**d**) food. The second is of a patient with moderately advanced cirrhosis with hepatomegaly. (**a**, **b**) abdominal wall, **c** ascites, **d** enlarged liver (hepatomegaly). The third is of a patient with far-advanced cirrhosis where one can note the snowstorm-like appearance of the liver. (**a**) abdominal, (**b**) enlarged liver. The fourth is of a patient with diffuse miliary melanoma of the liver. (**a**) liver with diffuse melanoma. The fifth is a thorium dioxide radiograph of a patient with nodular metastases in the liver. The sixth picture is the corresponding somagram of the same patient. **a** abdominal wall, **b** liver, **c** liver metastasis. (From Holmes et al. [35] with permission)

small catheters instead of large surgical incisions. Percutaneous abscess drainage was soon to become a very popular standard of care with radiologists, surgeons, and patients [47].

The fast development of this imaging modality makes it an essential part of every medical discipline where the possibilities are endless: three-dimensional reconstruction, CT guided biopsies and tumor ablation, and presurgical planning.

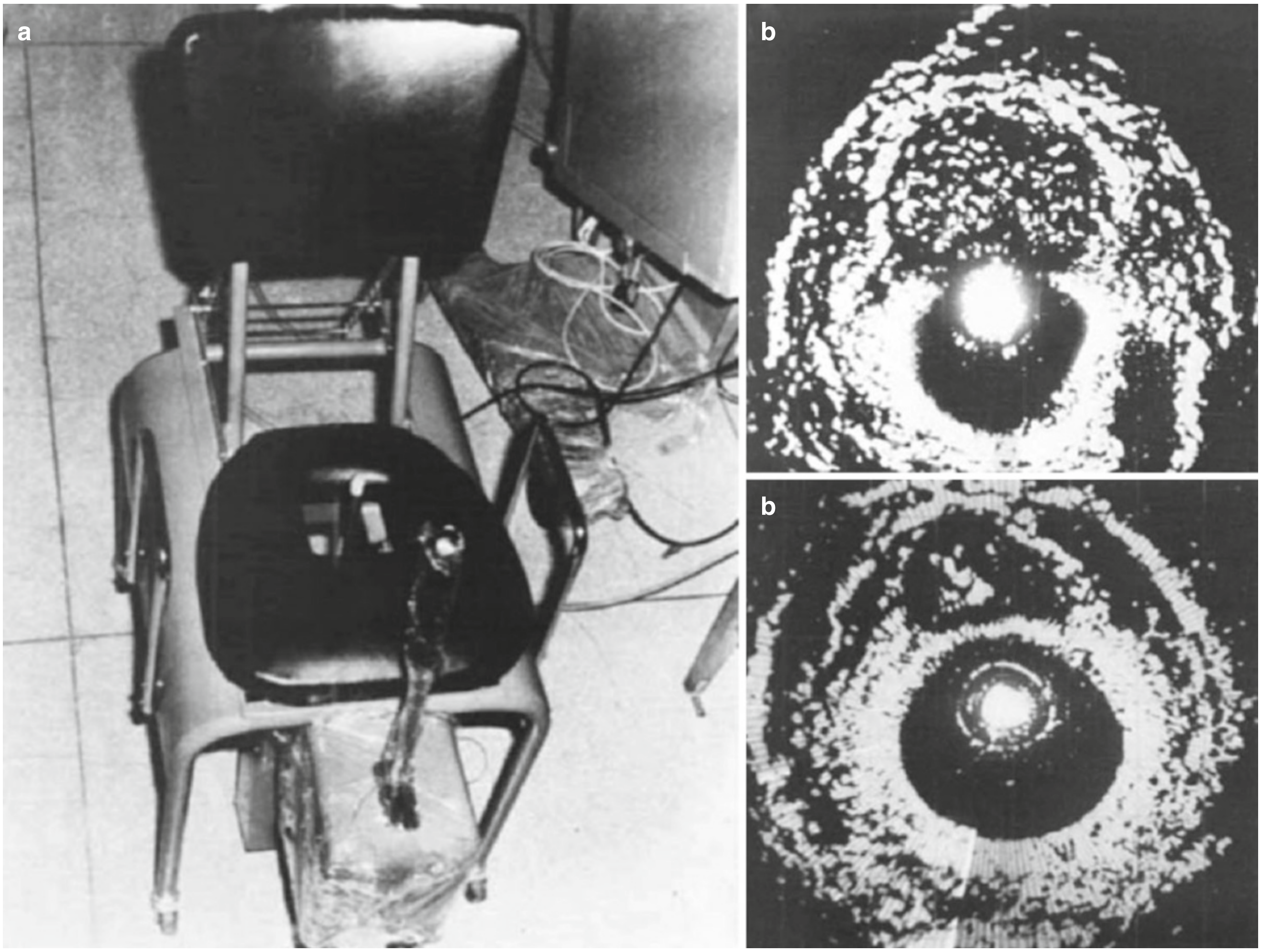

Fig. 1.7 (**a**) Watanabe's chair, (**b**) display of patient with BPH, (**c**) display of prostate with a nodule (From Watanabe et al. [36] Copyright 1957 John Wiley & Sons, Inc, with permission)

Magnetic resonance imaging (MRI) is one of the most important noninvasive imaging modalities in clinical diagnostics and research techniques that has evolved as a clinical modality over the past 30 years. The origins of MRI, or NMR (nuclear magnetic resonance), as it was termed in the past, however, can be traced back for over a century. Along the way, many scientists from diverse disciplines have made remarkable contributions that have brought the field to its present state. The success of MRI is in part brought about by the ability to image tissues with high resolutions in three dimensions, routinely down to 1 mm at clinical field strengths and smaller when necessary.

MRI was founded on the pioneering work of Felix Bloch and Edward Purcell in the field of NMR. These two independent groups discovered NMR almost simultaneously. Their investigations for which they received the Nobel Prize in 1952 focused on transition of magnetic nuclei and magnetic induction in bulk matter. In the same year, an American physicist by the name Herman Carr produced a one-dimensional MRI image [48].

In 1971, Raymond Damadian, a physician, at the Downstate Medical Center, State University of New York (SUNY), published a paper in *Science*, in which he reported that tumors and normal tissue can be distinguished in vivo by NMR [49].

In 1974, Paul C. Lauterbur, a chemist working in the United States, and Peter Mansfield, a physicist working in England, without knowledge of each other's work, described the use of magnetic field gradients for spatial localization of NMR signals. Their discoveries laid the foundation for Magnetic Resonance Imaging (MRI). For their contributions, Lauterbur and Mansfield were jointly awarded the 2003 Nobel Prize in Physiology or Medicine [50].

By 1975, Peter Mansfield and Andrew Maudsley proposed a line scan technique, which, in 1977, led to the first image of in vivo human anatomy of a cross section through a finger. In 1977, Hinshaw, Bottomley, and Holland succeeded with an image of the wrist [51] and Damadian et al. created a cross section of a human chest [52] More human thoracic and abdominal images followed, and, by 1978, Hugh Clow and Ian R. Young, working at the British company EMI, reported the first transverse NMR image through a human head [53]. Two years later, William Moore and colleagues presented the first coronal and sagittal images through a human head.

The Fonar Corporation introduced the first commercial unit designed by Raymond Damadian, at the meeting of the American Roentgen Ray Society in June 1980.

In 1980, Edelstein et al. from Aberdeen University in Scotland demonstrated imaging of the body [54]. A single image could be acquired in approximately 5 min by this technique. By 1986, the imaging time was reduced to about 5 s without sacrificing significant image quality.

As larger-bore magnets were produced and surface coil technology was applied, MRI of the spine and larger body parts or regions became possible, and organs in the chest, abdomen, and pelvis became the subject of investigations. With the advent of surface coils, contrast agents, and faster pulse sequences, the scope of information that can be derived from MRI has greatly expanded.

Shortly after the introduction of clinical MRI, the first contrast-enhanced human MRI studies were reported in 1981 using ferric chloride as a contrast agent in the gastrointestinal tract. In 1984, Carr et al. first demonstrated the use of a gadolinium compound as a diagnostic intravascular MRI contrast agent [55] Currently, around one-quarter of all MRI examinations are performed with contrast agents.

The rapid and continuous development of imaging and interventional techniques is utterly important to urology and other surgical specialties as they try to focus on diagnosis and minimally invasive approaches to historically major surgical and diagnostic procedures.

The field of interventional urology owes its roots to these discoveries and their continuous technological evolution.

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