Even in the absence of the marvels of communication provided by the modern electronic age, the world was not kept waiting long for the news of Wilhelm Röntgen’s discovery. During the last few days of 1895 Röntgen circulated prepublication copies of his epochal article—including prints of the radiographs—to a few European physicists, and within days the news had sped to London and from there to the United States (via transatlantic cable) and the rest of the world. By 7 January 1896 major newspapers everywhere had broken the story. The announcement was quickly followed by a rush of scientists eager to confirm the Würzburg professor’s work.

Some of the earliest experiments involved exposing gallstones and urinary tract calculi to the new rays in utero. Before January was over, Siegel had shown that both vesical and renal calculi were radiopaque (“just as opaque to Roentgen-rays as bones”). Although some skeptics despaired of ever demonstrating kidney stones in vivo because of the long exposure times involved, if indeed the rays could even penetrate large tissue thicknesses, others correctly predicted this would be accomplished. Sure enough, after repeated failures by himself as well as many other investigators, John Macintyre of Glasgow obtained the first diagnostic roentgen image of a renal calculus in a patient on 2 April 1896 (Fig. 9.1). The patient underwent surgical removal of the stone, and the report appeared in the 11 July 1896 issue of The Lancet. Despite the primitive nature of the image and the twelve-minute exposure required, Macintyre could well be considered the progenitor of uroradiology. He also had several other claims to fame: he organized the first department of radiology in the United Kingdom, invented cineradiography, and was a distant relative of the famous Scottish missionary to Africa, David I. Livingston. No less noteworthy is the fact that Macintyre’s interest in radiology was sparked by the skeptical Lord Kelvin’s challenge that he attempt to verify Röntgen’s original observations.

Before 1896 the practice of urology was based almost exclusively on cystoscopy—itself a relatively new development—as well as on laboratory and physical examination. Röntgen’s discovery changed urology forever, as
A flurry of reports confirming Macintyre's work followed on the heels of his seminal observations.\textsuperscript{17,18} In 1898 Longard reported having detected a ureteral calculus with the use of X ray.\textsuperscript{19} Between 1898 and 1900 the eminent Philadelphia roentgen-pioneer Charles Lester Leonard wrote a series of papers about urinary tract calculi and strongly supported the use of X rays for their detection.\textsuperscript{20,21,22} Occasional diagnostic errors such as mistaking phleboliths for ureteral calculi did not go unnoticed, however, and some radiologists came under fire for what was viewed as overly strong roentgen advocacy.\textsuperscript{23,24,25} Among the severest skeptics of the value of the roentgen ray were some of Europe's best known surgeons. Sir Henry Morris, the first surgeon to successfully remove a kidney stone, wrote to his colleague Harry Harris, "In my opinion the Roentgen Ray is a scientific toy in renal cases, and our practice of surgery ought to be based upon other factors in every case."\textsuperscript{26} Sir Henry may have been a bit of a technophobe. He also called the cystoscope a "toy" when he first heard about it.\textsuperscript{27}

Despite these occasional mistakes, it was not long before the public became aware of the advantages the new science provided in establishing a diagnosis of urolithiasis, and as early as 1897 patients suspected of harboring stones were beginning to request examination with the roentgen ray rather than submit to instrumentation for diagnosis.

From its inception in 1896 with a single photographic plate to its present status as a highly technological, rigorous, scientific discipline, the specialty of uroradiology has undergone a sustained, sweeping evolution. A case can be made for a simple classification of uroradiological history into three main periods: pre-urographic (1895–1929), urogramic (1929–1975), and post-urographic (1975–present). Because the dates of some events are uncertain and other events have prolonged gestation periods, the periods are arbitrary rather than hard and fast, and, of course, events in one period overlap those in another.

There are no two branches of medicine which are more closely associated and more interdependent, than urology and roentgenology.

-Hugh Young, 1928\textsuperscript{13}

Urology can be said to owe its existence as a specialty to the inventive genius of Thomas Edison and Wilhelm Conrad Röntgen.

-Ref E. Nesbit, 1956\textsuperscript{14}

With the discovery of the X ray in 1895 by [Wilhelm] Conrad Röntgen, urology became a truly enlightened field.

-Joseph Kaufman, 1964\textsuperscript{15}

Uroradiology has been an essential aspect of the practice of urology for many decades...Urologists and radiologists have worked closely for many years.

-John Libertino, 1984\textsuperscript{16}
PRE- UROGRAPHIC ERA (1895–1929)

For the thirty or so years after Macnayre’s demonstration of a kidney stone, uroradiology progressed slowly but steadily along two main lines: general radiographic technique and contrast examinations of the urinary tract. Although the earliest radiographic and fluoroscopic efforts were directed mainly at detecting kidney and bladder stones, attempts were also made to evaluate other factors, such as the size and shape of the kidney and renal mobility.29–30 Without contrast media, however, these efforts were of limited clinical value. Beam collimation by means of a cone that also compressed the abdomen was described in 1902 by Albers-Schönberg and helped greatly in improving detail (Fig. 9.2).31 As early as 1902 Mayou recognized the salutary effect of laxatives and cleansing enemas on the clarity with which bladder calculi could be visualized.32 Improvements in generator and tube design were rapid, and each new development resulted in shorter exposure times and more predictable as well as higher-quality images.33,34

Gustav Bucky’s introduction of the grid and its modification by Hollis Potter were enormous advances for abdominal radiology, which received a further boost from the gradual replacement of photographic plates by single- and then double-emulsion film and from the availability of dependable, effective intensifying screens.35,36

Thus abdominal roentgenology, progressing steadily, by the end of World War I had become a dependable technology capable of producing more than acceptable radiographs and had earned an important place in clinical medicine. What remained if radiology was to have a truly significant impact on urology, however, was the development of a suitable contrast medium capable of producing relevant diagnostic information while permitting safe parenteral and local administration.

The Introduction of Contrast Media

Stretching the definition somewhat, the first contrast study of the urinary tract was that performed by Theodore Tuffier, who in 1897 inserted a metal stylet into a ureteral catheter, rendering it opaque and thereby outlining the course of the ureter (Figs. 9.3a and b).37,38 The idea that Tuffier merely suggested opacifying a ureteral catheter but did not actually do so himself is incorrect, merely one of several myths surrounding early uroradiology that are still perpetuated. Contemporaries of Tuffier who worked in the same area in 1901 and are sometimes erroneously credited with having first demonstrated the course of the ureter roentgenographically include Loewenhardt, who passed a flexible lead wire through a ureteral catheter; Schmidt and Kolischer, who used lead wires without a catheter; and Illyes, who employed a silver
mandrin (but who also suggested that the same effect might be achieved by filling the catheter with bismuth subnitrate before inserting it). After Loewenhardt also recommended localizing the ureters first by fluoroscopy, so as to better position them for the radiographs.

Klose anticipated retrograde pyelography when he pointed out in 1904 that a suspension of bismuth subnitrate, if injected after the catheter had been passed rather than before, could also serve to fill the renal pelvis. Concerned with possible irritating effects of this suspension on the urothelium, however, Klose never attempted to do this. Ureteral catheters were nonopaque in those days, but Hurry Fenwick was able to produce radiopaque catheters by impregnating their walls with iron oxide. As surgeon to Saint Peter's Hospital for Stone in London, Fenwick accumulated a vast experience with urolithiasis. Appropriately, his textbook, *The Value of Radiography in the Diagnosis and Treatment of Urinary Stone*, published in 1908, was the first book dedicated to urinary tract radiology (Fig. 9.4). Rendering the course of the ureter radiopaque was obviously a big step forward in the ability to distinguish between ureteral calculi and phleboliths, obviating some of the problems encountered by Leonard and others.

Not all diagnostic pitfalls were overcome, however, and this problem appears to have been a particular sticking point among urologists. Fenwick mentioned the use of stereoscopy when it was difficult to be certain a stone was in the ureter, and other urologists developed their own “tricks of the trade,” such as buckling the ureter with a stiff stylet or making a second exposure with the X-ray tube angled. It seems hard to believe, but it was not

Fig. 9.3a Born of a peasant family in Normandy, Theodore Tuffier (1859-1929) rose to become one of Europe's best known surgeons and urologists. His idea of placing a metal stylet within a (nonopaque) ureteral catheter produced the first radiographs showing the course of the ureter.

Fig. 9.3b Radiograph of the course of the ureter in a living subject after catheterization with a catheter provided with a metal mandrin (1897). (Reprinted from Bruwer, A., Classic Descriptions in Diagnostic Roentgenology, with permission from Charles C. Thomas, Pub.)

Fig. 9.4 The first uroradiological textbook was written and published in 1908 by Hurry Fenwick, a prominent London urologist. Fenwick was an early advocate of both cystoscopy and roentgenology as diagnostic adjuncts to urology and developed the first radiopaque ureteral catheter.

(Author's collection)
until 1921 that the confusion was finally dispelled, when Sgaltzer and Hrynischak suggested using oblique views to differentiate ureteral stones from other pelvic calcifications.47-48 Interestingly enough, seventy years later, papers emphasizing the importance of oblique films in the diagnosis of ureteral calculi were still appearing.49

**Air as a contrast medium**

Contrast filling of a urinary viscus was first carried out in cadavers by von Zeissl and Holzknecht in 1902, but it remained for Wittek in 1903 to attempt the same thing in a live patient.50 Wittek used air as his contrast agent and succeeded in demonstrating vesical calculi.51 Wulff, however, was the first to employ a radiopaque medium in the bladder.52 In 1904, filling what was in all likelihood a huge diverticulum as well as the bladder itself with a suspension of 10 percent bismuth subnitrate in starch, Wulff cautioned against the use of air: "Aside from the actual danger involved in air insufflation...I also believe that my procedure gives much more precise results."52 Wulff was aided in his endeavor by Albers-Schönberg, who made the actual X-ray images himself. Despite Wulff's admonition, the fascination with gaseous contrast media persisted for many years and even extended to their use in the kidney.53,54,55-57 The famous Philadelphia radiologist George Pähler, for example, was a strong proponent of gas cystography for evaluating bladder tumors, but few others shared his enthusiasm. Much later, the use of gas as part of double-contrast cystography was advocated by Kniese and Schober, but this, too, failed to gain popularity.58

The theoretical appeal of gas, especially air, as a pyelographic contrast medium was understandable. Air was readily available and cheap, and gas embolism was not a serious consideration in the small volumes necessary to fill the renal collecting system. However, it was difficult to keep the pelvis distended with gas, and bubbles—which were frequent—were easily confused with pathological filling defects. It was apparent that at this time there was not yet a satisfactory agent for upper urinary tract visualization.

**Collargol: A silver standard**

In 1905 two German surgeons, Fritz Voelcker and Alexander von Lichtenberg, searching for a safe and effective radiopaque contrast medium for use in the urinary tract, published the initial account of their work with Collargol, a colloidal suspension of silver. The older of the two, Voelcker, was a brilliant if sometimes moody man, and although urological surgery was his special interest, he was primarily a skilled general surgeon (Fig. 9.5).59 In 1903, in association with his colleague, E. Joseph, he had been the first to describe the use of indigo carmine excretion as a test of renal function.60 Von Lichtenberg, his Hungarian-born assistant, would spend most of his professional life in Germany, where he would eventually become one of Europe's most respected urologists (Fig. 9.6). The idea of using Collargol was probably Voelcker's.61 As an experienced physician he knew that Collargol had been in use for some time as a local antiseptic and was undoubtedly familiar with its use in the eyes of newborns to prevent ophthalmia neonatorum.
Using 5 percent Collargol, Vöckler and von Lichtenberg identified, described, and illustrated the normal renal pelvis and calyces ("cup-shaped spurs"), nephropatis, hydronephrosis, and extrinsic ureteral obstruction, and they correctly predicted that renal tumors and renal anomalies could be recognized with their technique. They may not have fully appreciated the limited capacity of the renal collecting system, however, because their illustrations suggest that they overinjected many of their patients' renal pelvis and calyces, producing pyelocalyceal rupture, backflow, and marked discomfort. Indeed, in one patient, surgery—carried out twenty-four hours after the retrograde pyelogram had been performed—confirmed evidence of perinephric extravasation of the contrast material ("darkish coloration in the loose connective tissue at the kidney hilus and ureter").

Another historical myth surrounding the early days of uroradiology concerns the circumstances under which Vöckler and von Lichtenberg discovered Collargol pyelography. According to conventional lore, the idea came to them quite by accident when, while performing cystography, one of their patients—owing to vesicoureteral reflux—unexpectedly showed a pyeloureterogram on one of the X-ray plates. This tale appears to be as untrue as it is amusing. The real story is best told in the words of Vöckler and von Lichtenberg themselves: "From an abstract of a lecture we delivered on this topic in Meran, we gather that the abstractor has misunderstood us, since he seems to assume that we actually succeeded in revealing the renal pelvis by means of a simple filling of the bladder with Collargol." They went on to state emphatically that "it is not possible, even with the highest pressures, to force a fluid from the bladder into the ureters and renal pelvis." Although skeptical at first, urologists gradually warmed to retrograde pyelography, which soon gained worldwide acceptance and eventually became a mainstay of urological diagnosis (Fig. 9.7).

Numerous articles described the
pyelographic appearances of a spectrum of renal diseases, along with suggestions for modifications and improvements in technique. Particularly strong proponents of the method were Braasch in Minnesota (Fig. 9.8) and Uhle and Pfähler in Philadelphia, both in 1910. These investigators not only helped to standardize the technique of retrograde pyelography, but described the roentgen changes of most of the conditions known today, including inflammation, tumor, calculus disease, tuberculosis, congenital anomalies, obstruction, and autosomal dominant polycystic disease. In 1910 Uhle and Pfähler cautioned against distending the renal pelvis and, taking a cue from Baker, who had earlier accurately measured renal pelvic volume by gravity filling, recommended that the opaque medium be allowed to flow into the kidney by gravity rather than being hand injected.

For purposes of better retention of contrast, in 1913 Schram recommended the moderate Trendelenberg position, while Fowler emphasized the need for an erect view when assessment of upper tract emptying was desired. Other authors touted the use of fluoroscopic localization ("pyeloscopy," "uroscopy") to aid in centering the beam for the roentgen exposures. In 1914 Thomson-Walker published a thorough review of pyelography, while the next year marked the appearance of William Braasch’s Pyelography, the first textbook devoted to the subject, based on the author’s experience with more than a thousand cases (Fig. 9.9). By this time, retrograde pyelography had become inextricably woven into the practice of medicine.

Although Collargol was now the contrast medium of choice for pyelography, it was by no means problem free. Most troublesome were the reports of severe renal damage and even deaths following its use. In 1914 Mason reported several cases of renal infarcts following Collargol administration, while others warned of the danger of parenchymal necrosis. Several observers called attention to the persistence of silver colloid in the perinephric tissues for many days after pyelography. While it appeared that significant renal damage could be avoided by careful technique, there was no dearth of reported complications. In Zindel could find eleven deaths associated with Collargol pyelography and many more cases of severe renal dam-
tium chloride in 1924, as well as oily suspensions of bismuth (xeroform) in 1913 and iodine (Lipiodol) in 1922. Each of these agents, however, was beset by one or more problem, which prevented its acceptance for pyelography. In 1915 Burns introduced thorium nitrate, the first soluble salt, and, because the carcinogenic effects of thorium were not well appreciated then, it appeared for a time that an acceptable substitute for Collargol had finally been found (Fig. 9.10). Later, however, it was learned that thorium nitrate caused astringent, irritant, and thrombotic problems (probably unrelated to its radioactivity), and it was eventually abandoned after a two- or three-year run of popularity.

This loss proved to be a blessing, because the rejection of thorium nitrate prevented countless tragedies that would have undoubtedly followed its introduction on a large scale. However, thorium, in a colloidal suspension (Thorotrast), was reintroduced in 1928. Although the hazards associated with its use were known by then, they were less publicized in Europe than in America. Perhaps this explains why almost all of the early reported cases of thorotrast-related kidney neoplasms emanated from Europe. With its chemical inertness and almost total absence of acute toxicity, it is easy to appreciate Thorotrast’s appeal. Fortunately, better contrast media were available by 1928, with more on the way.

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**Figure 9.10** Advertisement advocating the use of thorium for pyelography and cystography which appeared in the *Journal of Urology*, June 1917. (Reprinted with permission from the *Journal of Urology*.)

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**Other contrast substances**

Attempts to replace silver with less objectionable metals resulted in trials of sodium bromide in 1918, lithium iodide (Umbrenal) in 1921, and strontium.
and Thorotrust's time in the sun was limited. As it was, however, as many as fifty thousand patients may have received it before it was finally withdrawn.98

The bad reputation of retrograde pyelography began to lift in 1918 when Cameron first published his carefully detailed work showing the lack of renal toxicity of sodium and potassium iodide. He eliminated the potassium salt because of its effect on the heart.99 Sodium iodide in the concentrations proposed was less hypertonic than any other contrast medium. Follow-up studies in 1920 demonstrated that sodium iodide produced no discernible renal changes in animals, that no ill effects followed its inadvertent entry into the circulation, and that clinical experiences were extremely favorable.100,101 As the results of these and additional studies, especially those of Rubritius, Graves, and Davidoff, became known, the case for sodium iodide grew stronger and the case for silver weaker.102,103 Within a few years, sodium iodide had established itself as the contrast medium of choice for pyelography, and it would remain so for a decade or more until replaced by a new generation of agents designed for excretory urography. The romance with silver was over.

The long search for improved pyelographic contrast media was not without serendipitous benefits. One notable example was the work of Graves and Davidoff, which eventually led them to the study of vesicoureteral reflux. The existence of vesicoureteral reflux has been known for over a hundred years and had been clearly demonstrated in cystography by Kretschmer as early as 1916 (and possibly earlier by Legeu and Papin, who claim to have been the first to show reflux radiographically). But it was the vigorous investigations of Graves and Davidoff (an offshoot of their studies of contrast media), along with those of Bumpus, that led to a better understanding of the mechanism of reflux and a fuller awareness of its association with pyelonephritis.104 Despite his early work in uroradiology, Davidoff would go on to become one of America's best known neurosurgeons. Always maintaining an interest in radiology, however, he coauthored two classic textbooks on pneumoencephalography, the first with neuroradiologist Cornelius Dyke.105,106,107

Urethrography

As upper urinary tract imaging has advanced, roentgenography of the lower tract also drew early attention. Investigations of the urinary bladder as early as 1908 have been mentioned already.108 The first report of urethrography was in 1910 by John Cunningham, a Boston urologist who injected 50 percent Argynol into strictured urethras of male patients. Cunningham wedged the syringe directly into the external urethral orifice and retained the contrast medium in the urethra with a clamp of his own design (Fig. 9.11).109,110 He was unimpressed with the clinical value of urethrography, perhaps because his patients were not optimally positioned and their urethras not uniformly distended. There is nothing to indicate he used it in his practice after his initial description. Other pioneers of urethrography writing in 1912 were Uray and Maitingot in Europe, where roentgenographic evaluation of the urethra was greeted more enthusiastically than the United States.110,111 One of urethrography's staunchest advocates was Langer, who described the normal urethra in great detail as well as abnormalities of the prostate and Cowper's glands.112

As in the upper tract, much of the early work on urethrography involved the search for a suitable contrast medium. In addition to colloidal silver, most of the opaque media of the day, including bismuth, barium, iodized oils, and halide salts, were tried but eventually replaced by the media for urography.113 Even thorium salts found some short-lived support.114 The existence of urethrocavernous reflux was known quite early, and warnings were raised about embolization from insoluble oils or emulsions and idiosyncratic drug reactions.115,116,117 In 1913 Legeu and associates were the first to use oblique views, while Knutsson, Chevassu, and others designed special instruments that permitted radiologists to distance their hands from the X-ray beam.118,119,120 In 1921 both
Haudek and Kurtzahn maintained that the X-ray exposure should be made during contrast installation rather than after, if there was to be hope of visualizing the prostatic urethra.\textsuperscript{121,122}

In 1921 Glingar appears to have been the first to carry out voiding urothography, a technique that gathered support from a number of physicians who believed that this approach surpassed the older retrograde method.\textsuperscript{123,124,125} Dressler, Langer, and others disagreed, however, and for several years an internecine controversy brewed over the issue.\textsuperscript{126,127} Puhl helped to settle things in 1930 by emphasizing that the two methods were complementary, rather than competitive. He made it clear that the retrograde method was better for studying the anterior urethra, while the voiding study better demonstrated the posterior urethra.\textsuperscript{128}

William Belfield in 1913 was the first to image the seminal vesicles.\textsuperscript{129} Already famous by then for his great surgical skills (Belfield is said to have performed in 1886 the first elective suprapubic prostatectomy in America), the multi-talented Chicago surgeon was also a pathologist and microbiologist with a keen interest in seminal vesiculitis.\textsuperscript{130} Hoping that seminal vesiculography might provide him with a firmer diagnostic grasp on vesicular diseases, he cannulated the vas through a scrotal incision and injected 4.5 cubic centimeters (cc.) of Collargol. The findings on vesiculography proved to be nonspecific, however, and of minimal clinical help, and this procedure never gained great favor.

In 1920 Hugh Young described a technique of vesiculography by means of endoscopic catheterization of the ejaculatory ducts, but this innovation proved to be too tedious, time-consuming, and clinically unrewarding for most urologists, who quickly lost interest in trying to duplicate either Young's work or Belfield's.\textsuperscript{131}

**THE UROGRAPHIC ERA (1929–1975)**

Despite the fact that retrograde pyelography had become nearly indispensable in urological practice, it was not an ideal diagnostic modality and could never become one as long as it required cystoscopy, ureteral instrumentation, and, in many cases, general anesthesia for its implementation. Urologists had long appreciated the need for a less invasive, more comprehensive urological screening test. The
fact that it might be possible to accomplish this by means of an intravenously (or even orally) administered agent was more than fanciful. It had been known for some time, for example, that after the performance of retrograde pyelography with sodium iodide, contrast could sometimes be detected in urine from the opposite kidney; indeed, occasionally a pyelogram could be observed in the uninjected kidney.\textsuperscript{132,133}

Since pathways of backflow from the kidney to the general circulation had been demonstrated as early as 1856 by Gigon and further elucidated by later researchers such as Poirier in 1891, Lewin in 1897, and Marcus in 1903, the concept of renal opacification by excretion of contrast media was not exactly foreign to experienced observers.\textsuperscript{134} Thus, it must not have come as a great surprise to Earl Osborne and his co-workers at the Mayo Clinic to observe faintly opacified urinary tracts in patients with syphilis who were undergoing treatment with relatively large doses of intravenously administered sodium iodide (50 to 250 cc. of a 10 percent solution). In fact, the study was done prospectively with the hope that diagnostic visualization of the urinary tract would be forthcoming (Fig. 9.12).\textsuperscript{135} Credit for the notion that such opacification might be possible probably belongs to the brilliant physician and pharmacologist Leonard Rowntree, although such credit has been disputed (Fig. 9.13). Grainger stated that the idea originated with Osborne, a dermatologist, who allegedly noticed serendipitously that the bladder urine was roentgenographically opaque in some of his syphilitic patients who had been treated with large oral and intravenous doses of sodium iodide. Osborne himself, however, attributed the idea to Rowntree: "It occurred to one of us [Rowntree] that if, in roentgenography of the urinary tract, advantage could be taken of the fact that sodium iodid [sic], after its introduction into the body, is normally excreted in the urine, roentgenograms of the kidneys, ureters and bladder might be secured without the need of catheterization."\textsuperscript{136}

Besides Rowntree and Osborne, the other participants in the study were Charles Sutherland, a radiologist, and Albert Scholl, a urologist (Figs. 9.14a and b). Unfortunately, the roentgenograms they obtained (some after oral administration of sodium iodide) showed only faint urinary tract opacification, never approaching the level necessary to exert a clinical effect (Fig. 9.15). The door had been opened, but for some reason few if
any investigators, not even the Mayo group, ventured through. Perhaps the
doses of iodide were thought too large, but whatever the cause, no further
progress was made in excretory urography over the next five years.

To be sure, a few observers, including Rosenstein and von Lichtenberg,
Lenarduzzi and Pecco, and Volkman, repeated Osborne’s work in the mid-
1920s, but failed to expand upon it.137,138,139 Perhaps the most promising
work was that of Roseno who in 1928 cleverly combined sodium iodide with
urea (Pyelognost); some of his films were quite impressive, but the quality of
the studies inconsistent.140 Between 1927 and 1929 Hrynischalk tried more
than fifty halides, and Zeigler and Kohler tried large doses by mouth, but
neither they nor the others could consistently produce diagnostic urinary
tract opacification.141,142,143 No less a figure than von Lichtenberg himself, by
now the leader of European urologists and an early strong supporter of the
concept of urography, was beginning to think the idea was an impossible
dream.144 But in what was to become one of the most interesting tales in the
chronicles of radiological history, fate was about to step in.

The Discovery of Excretory Urography

In 1928 Moses Swick (Fig. 9.16), a
bright young house officer at Mount Sinai
Hospital in New York, was offered the
opportunity to study abroad by his chief,
Emanuel Libman (of Libman-Sacks’ dis-
ease fame) (Fig. 9.16). Swick, an aspiring uro-
ologist, chose to use his
Libman fellowship in the
clinic and laboratories of
Leopold Lichtwitz, a high-
ly respected internist in
Hamburg, Germany.145,146
Lichtwitz, who was in-
terested in infectious dis-
cases, was studying the
effect of newly synthesized
antibacterials on coccical
infections of the gallblad-
der and kidney, and Swick
was eager to help him.147

Fig. 9.14a Charles Sutherland
(1897–1951). Sutherland, a radiolo-
gist, joined the staff at the Mayo
Clinic upon the completion of his
training in 1926 and remained there
for his entire professional career.
(Courtesy of the Center for the
American History of Radiology,
Reston, Va.)

Fig. 9.14b Albert J. Scholl
(1890–1982). Scholl left the Mayo
Clinic in 1924 and entered the prac-
tice of urology in Los Angeles. He
was affiliated with the University of
Southern California for most of his
professional career and was presi-
dent of the American Association of
Genito-Urinary Surgeons in 1953.
He died on 16 May 1982. (Courtesy
of the Center for the American
History of Radiology, Reston, Va.)

Fig. 9.15 Original radiograph from
Osborne et al. showing good opaci-
fication of the urinary bladder follow-
ing intravenous injection of 200 cc. of
10 percent sodium iodide. (Reprinted
from Brucker, A., Classic Descriptions
in Diagnostic Roentgenology, with
permission from Charles C. Thomas,
Pub.)
Lichtwitz was fortunate to have made friends with a chemist, Arthur Binz of Berlin, who, with his associate, Curt Rath, had synthesized hundreds of compounds with potential therapeutic effectiveness and graciously provided Lichtwitz with a smorgasbord of new and exciting agents.

Binz was to become another major player in the drama that evolved over priorities in excretory urography, and the evolution of his role bears telling. Shortly after World War I he succeeded to the directorship of the chemical division of the State Institute for Experimental Therapy in Frankfurt where, years earlier, Paul Ehrlich had synthesized the first chemotherapeutic agent, the antispirochetal arsenical, Salvarsan 606. With his focus on preparing more effective antiluetic drugs, Binz and his associates discovered that incorporating arsenic (or other metals) into a pyridine ring markedly lessened its toxicity. Substituting iodine in place of arsenic, they created a new group of compounds that seemed to be just as antimicrobial as their arsenic-containing relatives, but less toxic. One of these compounds, Selectan, was found to be particularly good in treating coxal infections of cows’ udders. After altering it chemically to increase its solubility (from 4 percent to 10 percent), Binz, who by this time had moved to the Agricultural College in Berlin, forwarded the new agent, Selectan Neutral, to Lichtwitz as well as to several other physicians.148

During the evaluation of Selectan Neutral in rabbits, Swick noticed that the animals’ urinary iodine concentration was high and wondered whether the urine might be radiopaque.149 150 When later work in animals and humans confirmed that it was, Swick persuaded Lichtwitz to let him switch his attention from the therapeutic to the diagnostic potential of Binz’s drugs.

Further testing showed Selectan Neutral to be unsatisfactory for clinical use. The pyelocalyceal systems and ureters were poorly seen, and distressing symptoms, including nausea, vomiting, diplopia, and headache were frequent. Nonetheless, Swick and Lichtwitz were encouraged enough to press on with the search for a more suitable contrast medium. At an ensuing meeting with Binz, Swick postulated that the nature of the adverse effects of Selectan Neutral, especially the diplopia, might be attributable to its methyl radical and asked whether it could be replaced. Binz offered two alternative agents, both di-iodinated compounds, but they proved too poorly soluble for intravenous use. Tiring them orally did not work either, and these two were promptly dropped.151 152

At this point, a decision was made which both Swick and his mentor, Lichtwitz, would come to rue. Because Swick thought the research would move along faster in a hospital with a larger urological population, he persuaded Lichtwitz to ask von Lichtenberg, whose urology service at St. Hedwig’s Hospital in Berlin was probably the largest in the world (with, at one point, more than 250 urological beds), whether he could transfer his investigations there. Because anything having to do with urinary tract opacification was of great interest to von Lichtenberg, he was receptive to the proposal. An added benefit to Swick, of course, was that moving to Berlin would put Swick clos-
home at once, fascinated by the prospects that his twenty-year
search for the holy grail of uro-radiology might be over at
last.  

There are many versions of what happened next. The facts
seem only slightly hazy; it is the interpretations that vary
greatly. Binz and von Lichtenberg saw things one way; Lichtwitz and
Swick, another. These differences were deep and irreconcilable and would,
for the rest of their lives, indelibly scar the participants.

Upon reviewing Swick’s results, the ebullient von
Lichtenberg could hardly wait to announce the discovery to
the world. He would, of course, present the results himself at
the ninth German Urological Congress in Munich, only a few
months away. Having been raised in the strong Germanic tradition of
gemeinschaft, wherein the professor was
the lord of the fiefdom and all others
subservient to him, it never occurred to
the baron that anyone else should make
this presentation or be first author on
the landmark paper to follow. As the
chief, the honor belonged to him. The
young American, uninhibited by the
strict teutonic professional code, had
other ideas. As the one whose brainchild
this was and the one who had conducted
the painstaking experiments and laborious
testing (while his chief was more
than 3,000 miles away), should not he,
ethically and morally, receive most of the
credit for excretory urography, and did
he not deserve the honor of making the
first oral and written presentations to the
scientific community?

The dispute was heated but was
momentarily resolved at a conference
attended by the protagonists, Swick and
von Lichtenberg, as well as Lichtwitz, his
assistant Renner, and von Salle, the editor of Klinische Wochenschrift, the journal
in which the proceedings of the urological
congress were to be published. A
compromise was reached. Swick would
make the first presentation detailing the
appared after the congress. Swick’s paper appeared first in Klinische Wochenschrift followed by joint papers by von Lichtenberg and Swick which, by now, included data on eighty-four patients (Fig. 9.18). Needless to say, these publications caused a stir, but they were not the only items of radiological interest in that issue. By a remarkable coincidence, the article immediately preceding Swick’s was by Werner Forssmann and contained the first-ever description of (self) cardiac catheterization (Fig. 9.19). Forssmann, who shared the Nobel Prize in medicine in 1956, was like Swick a urologist by training, but was unable to establish a successful urological practice in a major university or large city. Another irony of the time concerned a paper presented by dos Santos at the ninth congress. Dos Santos’s presentation, of course, was the first announcement of his soon-to-become-classic work on translumbar aortography, but, unfortunately, the young Portuguese surgeon never got the development of Uroselectan and would show a few roentgenograms. A joint offering on the clinical applications of excretory urography, presented by von Lichtenberg, would follow. According to Grainger, who with Marshall has exquisitely chronicled the details of these events, “It is probable that without Lichtwitz’s support, Swick would never have been recognized as a major contributor to this work.”

As scheduled, the publications
recognition he deserved. His work was completely upstaged by the spectacular results of Swick and the Germans and was, for the moment, overlooked. The same fate befell the Italian investigator, Roscoro, who, one year after his earlier presentation at the eighth German Urological Congress in Berlin, was back with new and improved results with Pyelognost, but these too were overshadowed by the reports of Urosectan.

Von Lichtenberg never forgave Swick for what he perceived as insufferable insubordination, and one can only wonder how much of a hand the Berlin uroneister had in seeing that Swick's name was all but blotted out in future references to urography. In 1930, for example, shortly after young Swick had returned to New York, the American Urological Association (AUA) held its annual meeting there. The guest of honor was von Lichtenberg, who was accorded a hero's welcome as he presented the first paper in America on "The Principles of Intravenous Urography." Not only was Swick's name barely mentioned, he was not even invited to the meeting!

Meanwhile, in Germany Schering took over the commercial manufacturing of Urosectan (then marketed as Iopax), while Binz and Roth were busy making new iodinated pyridines (Fig. 9.20). They succeeded in synthesizing two important new derivatives: Urosectan B (Neo-Iopax) in 1930 and, two years later, Diodrast (Diodone), both di-iodinated compounds with good solubility and low toxicity (Figs. 9.21a and 9.21b). Diodrast and Neo-Iopax were to become the standard contrast media for invravascular use for the next twenty years. Meanwhile, von Lichtenberg luxuriated in the limelight of intravenous urography for which he took credit (and which some believed to have been an achievement important enough to merit consideration for a Nobel prize). The German professor's fame grew greater as he received countless accolades and awards from all over the world.

But Swick was far from finished. Hurt by being shoved into the background but determined to continue his work nonetheless, he pursued other ideas for contrast media. Despite the trials of building a urological practice, he managed to find time to team up with Vernon Wallingford, a chemist at the Mallinckrodt Chemical Works in St. Louis. Abandoning the Binz pyridine-based model in favor of a new molecule configured from benzoic acid, the two brought off a biochemical tour de force;
not only did they discover Hippuran, a mono-iodinated benzoic acid derivative, but they laid the chemical groundwork for the next generation of contrast media: tri-iodinated benzoic acid derivatives.\textsuperscript{171} (It took a full twenty years, however, before Wallingford and Hoppe finally unlocked the secrets of making nontoxic tri-iodinated contrast media from benzoic acid.\textsuperscript{172,173}) Although Hippuran itself did not live up to expectations because of its low iodine content and poor tolerance in high doses, the potential impact of its synthesis was quickly appreciated. In 1933 Swick and Wallingford received the prestigious Billings Gold Medal of the American Medical Association for this discovery.

Ironically, Hippuran, nearly valueless as a radiographic contrast agent, proved to be a superb molecule for determining renal plasma flow (paranephrohippurate) and in its radioactive form (\textsuperscript{131}I-Hippuran) became a valuable agent for estimating renal tubular function.\textsuperscript{174} Diodrast and Neopan dominated the urographic scene until 1952, when they were replaced by the first tri-iodinated contrast medium for urography, Wallingford's acetrizoate (Urokon).\textsuperscript{175,176,177}

The introduction of the safer compound, diatrizoate (Hypaque), in 1954 was a major advance, but diatrizoate was later forced to share the market with the newer and popular iodotriaminate (Conray) introduced in 1968.\textsuperscript{178,179,180} Three decades later, diatrizoate and iodotriaminate are still the dominant ionic contrast media, as well as the radiopaque materials most commonly used for retrograde pyelography.

Who really deserves the credit for discovering excretory urography? In the minds of the embittered von Lichtenberg...
and Binz there was no doubt at all.\textsuperscript{181,182} To them, Swick was nothing more than a laboratory assistant out to usurp the honors rightfully belonging to them.\textsuperscript{185} But, realistically, could a young American doctor in a foreign country really slip-flam the tough Prussian medical establishment? Would von Lichtenberg have permitted Swick to make his presentation and write his manuscript alone if the senior professor had not felt that Swick’s role was preeminent? Probably not. Lichtwitz likened the priority issue to a three-legged stool with each man playing an indispensable role, but he reserved the main distinction for Swick: “To Dr. Swick of New York we owe the Uroselectan method.”\textsuperscript{184} Grainger, too, who has given this matter a great deal of study, came down on the side of Swick: “I think the record should now be put straight. Swick should be recognized as the man who, in Berlin in 1929, in the department of Professor von Lichtenberg, introduced clinical intravenous urography as a practical procedure.”\textsuperscript{185}

Years later, C. E. Alken, one of von Lichtenberg’s last assistants and a loyal disciple, admitted that the “honors of the discovery are [Swick’s].” He argued, though, that von Lichtenberg’s genius was to “recognize immediately the importance of the method” and to “successfully introduce the new method into clinical usage.”\textsuperscript{185}

It was never clear whether the hope of discovering a practical agent for excretory urography was in Swick’s mind when he went to Europe in 1928 or whether the discovery was entirely serendipitous. The available evidence suggests the latter, but in fact it matters little whether it was by fortune or design. What is important is that, when handed the opportunity, Swick, who was undoubtedly familiar with Osborne’s work, was quick to make the most of it. Lichtwitz put it well:

Important as is the existence of preparations [i.e., new compounds] they become valuable only when the right person takes them for a special purpose....The preparations of Professor Binz were tested for the same purpose before Dr. Swick began his studies (without his knowledge) by a man of great experience in research work—without sufficient results. Between the important work of chemical preparation and final success, there came the hard work of a clever and energetic man, one with the deepest devotion to and greatest passion for research work.\textsuperscript{187}

Perhaps Lichtwitz should also have pointed out that there was more than enough glory to go around.

While only a few insiders knew the truth, the vast majority of American and European physicians remained oblivious to Swick’s work. For many years it appeared that this oversight would never be corrected, but thirty-five years later the record was put straight at last. Almost entirely as a result of the diligent, persistent efforts of one man, Victor F. Marshall of New York, the facts were unearthed and eventually disclosed.\textsuperscript{188} Marshall, then professor and chairman of the department of urology at Cornell Medical School, motivated by stories he had heard about Swick’s role, became determined to unearth the truth and set about collecting relevant papers, documents, diaries, and first-person accounts from any and all persons with pertinent information relating to this near-forgotten tale. After several years of painstaking research Marshall was convinced that Swick had been unfairly treated by organized medicine, urology in particular, and he undertook a one-man crusade to convince the leaders of American urology that they had been parties to a grave injustice.

Because of Marshall’s evidence and professional stature, his voice eventually fell on sympathetic ears. In 1965 as part of the award ceremony accompanying the presentation of the prestigious Valentine Award by the New York Academy of Medicine, Swick finally received his just recognition. Not only did he receive the Valentine Medal, but as part of the ceremony he also received tributes—and sincere, eloquent apologies—from a number of America’s leading urologists and spokesmen for
organized urology, including Miley Wesson, William F. Brasch, Fred Foley (of Foley catheter fame), William P. Herbst, Hermon C. Bumpus, and Abe Goldstein.\(^{189}\)

So, at last, Moses Swick received the honor so long withheld from him through bias, jealousy, politics, and just plain ignorance. He was deeply touched by the collective expression of appreciation he heard that night.\(^{190}\) Certainly, it went a long way toward erasing the accumulated hurt of thirty-five years.

For the rest of his career Swick remained in New York in the private practice of urology. His research activities were limited after his work with Hippuran, but he retained an active interest in academics and clinical investigation. In later years Swick received many honors, including honorary membership in the Society of Uroradiology in 1974 and an honorary doctor of medicine from the Free University of Berlin in 1975. He died in 1983 at the age of eighty-five. He is memorialized by his parent institution, Mount Sinai Medical School of New York, with an annual lecture in his name.

Von Lichtenberg, who estimated he performed more than thirty thousand operations in his lifetime, maintained his hectic surgical practice in Berlin until 1936.\(^{191}\) That year, disturbed by the political changes taking place in Germany, von Lichtenberg, who was part-Jewish and had already been forced to relinquish his teaching activities, moved to Budapest.\(^{192}\) Prescient as usual, he soon realized that before long all Europe would be immersed in conflagration, and fearing for the welfare of his wife, who was also Jewish, and children, emigrated with them to Mexico in 1939. Von Lichtenberg died in Mexico City in 1949, having actively practiced urology there until shortly before his death at age sixty-nine.

Arthur Binz continued his work on the antibacterial properties of pyridine derivatives, even after his retirement from the Berlin Agricultural College in 1935. He made several speaking tours of the United States in the late 1930s, but declined an opportunity to stay on for an extra year as a guest investigator at Philadelphia's Franklin Institute, feeling that an unfriendly atmosphere confronted all Germans in the United States at that time. He died in Germany in 1943 at the age of seventy-five.\(^{193}\)

Leopold Lichtwitz's career was another casualty of the Hitler regime. Forced to leave Germany in the early 1930s, he settled in New York, where he practiced medicine at Montefiore Hospital. He died there in 1949 at age sixty-nine.\(^{194}\)

Introduction of Nonionic Contrast Agents

Although diatrizoate and iothalamate all but monopolized the contrast media world for nearly thirty years, that world was not perfect. Despite excellent safety records, occasional serious reactions accompanied the use of these agents, and the search for even safer media never abated.\(^{195}\) One person who was convinced that better contrast media could be designed was Torsten Almén, a young Swedish radiologist, who was particularly concerned about the pain accompanying contrast media injection during arteriography (Fig. 9.22). Almén, who liked to take an occasional dip in the Baltic, was struck by the fact that swimming under water with his eyes open in the isotonic Baltic Sea never caused his eyes to hurt, while the same activity performed in the hypertonic Atlantic or Mediterranean regularly produced pain. He theorized that hypertonicity damaged endothelial membranes by drawing water out of the delicate lining cells and wondered whether hypertonicity might also be the main cause of pain during arteriography.\(^{196}\)

The Swedish investigator soon got his opportunity to find out. Arriving in Philadelphia in 1967 as a postdoctoral fellow in the laboratories of Herbert Stauffer, then chairman of the department of radiology at Temple University School of Medicine, and Peter Lynch of the department of physiology, Almén had a choice of research projects: he could either work on an improved model of a steerable angiographic catheter he had previously designed, or he could look into the relationship
told to get rid of the bats. I found a colony of bats hanging on the backs of the Acta Orthopaedica Scandinavica. I did not know if this journal was the least borrowed in the library or if they were the books with the best circulation. I brought the bats back to my refrigerator and when spring came, they flew home to New Jersey.296

Not being able to interest anyone in producing low-osmolality contrast media, Almén was left to his own devices. Because he was not a chemist and knew little about designing such things, he bought some organic and colloid chemistry textbooks and taught himself the essentials. He saw that replacing the carboxyl group with a nonionising amide would partially satisfy his requirements, and he drew up a hypothetical formula for what would later become metrizamide (Anipaque), the prototype of nonionic contrast media. Poorly soluble, metrizamide was of limited usefulness for urography and was eventually followed by the polyhydroxylated highly soluble, second generation agents, including iohexol (Omnipaque), iopamidol (Isovue), and ioversol (Optiray).296

Unfortunately, Almén was once again forced to suffer those twin maladies so common to original thinkers, rejection and frustration. It was several years before he was able to interest any pharmaceutical company in his ideas—even with a molecular blueprint in hand. Eventually, a small Norwegian concern, Nyegaard A/S and Co., was persuaded to listen. The perspicacity of its director

between toxicity and toxicity of contrast media.297 After thinking it over he decided on the latter.

Almén used bats to test his hypothesis. Working with Professor Mimi Weideman, he dripped contrast media onto the very thin bat wings and studied the effects on microcirculation (Fig. 9.23). The results proved conclusively that his osmotoxicity theory was correct. As described by Almén:

"The experiments taught me the relative importance of the osmotoxicity of the contrast media: the higher the osmolarity the higher the inhibiting effect on vasomotions in arteries, veins and lymphatics; and, also, the higher the viscosity of the red blood cells the slower their flow through capillaries and other small vessels."298

The demands and tedium of the laboratory were occasionally interrupted by humorous interludes, as the following account by Almén shows:

After the experiments the bats were released through an open window to fly home to their mine in New Jersey. But it was too cold to fly home that winter of 1987, and instead the bats found an open window in the basement of the medical school library. After a while the librarians did not dare enter the basement because of the bats. The culprit, me, was located and

Fig. 9.22 Torsten Almén conducted his initial research on low osmolality contrast agents at Temple University Medical School's Department of Radiology. For much of his work he relied on the study of the vasculature of the bat's wing. Here he is seen during his days in Philadelphia as a post-doctoral fellow (1967-1968).

Fig. 9.23 Professor Mimi Weideman (Department of Physiology at Temple) examining bat wing preparatory to exposing it to various contrast agents to determine effects on capillaries and lymphatics. (Author's collection)
of research and development, Hugo Holtermann, was rewarded years later when the little known Nyegaard Company evolved into the giant international Nycomed organization, largely on the strength of low-osmolality contrast media.

In addition to being the discoverer of a new and important class of biological compounds, Ahmén holds at least one other distinction; he was, incredible as it may seem, the first radiologist to play a major role in the synthesis of any contrast medium.201 And this not until 1967, seventy-two years after Röntgen!

Although today's standards it may seem incongruous that a radiological specialty—uroradiology—was born and nurtured largely out of reach of radiology, it should be recalled that prior to 1920 there were relatively few radiologists, and of those who labeled themselves as such, most practiced this specialty only part time, while some lacked even the rudiments of a medical education. While radiology labored to overcome its undistinguished image, urologists and would-be urologists made off with the honors, including that of the discovery of excretory urography. It all changed after 1967, however, and the primacy of radiology thereafter is well recorded. Still, the well-deserved priorities accorded nonradiologists such as Rosenstein, dos Santos, and later Winter, for their important uroradiological discoveries all occurring after 1920, illustrate again the curious fact that radiologists failed to gain dominance over their own specialty until, as in the case of uroradiology, it was more than forty years old.202,203,204

The Evolution of Excretory Urography

Although excretory urography was a urological creation greeted with much fanfare, it was slow to be accepted by most urologists who viewed it as distinctly inferior to retrograde pyelography—an attitude that persisted for many years. Elkin has neatly summarized some of the prevailing attitudes among urologists—and even a few radiologists—of the time.205 Using their degree of confidence in the urographic detection of renal neoplasms as a barometer, Elkin found urologists' opinions about urography to range from bare tolerance to hostile rejection. He noted that urologists such as Braasch, Griffin, Fetter, and Mintz were generally underwhelmed by urography's contribution to the management of renal masses and claimed that most patients still required surgery for diagnosis.206,207,208 Examining uroradiological textbooks of the period, Elkin found that two of the most popular, *The Urinary Tract*, published in 1945 by Kerr and Gillies, and *Clinical Urography*, published in 1951 by Braasch and Emmett, relied almost exclusively on retrograde pyelograms to illustrate their respective sections on renal malignancies.209,210 Interestingly, a check of subsequent editions of these two works reveals that a quarter of a century later the proportions of retrograde pyelograms, while much less, still exceeded 50 percent in each work.211,212 As late as 1950 David M. Davis, an influential professor of urology at Jefferson Medical College, was outspokenly critical of urography: "The intravenous urogram in practically every case [of renal tumor] represents a complete loss of time and money, and, in my opinion, may well be entirely abandoned."213 In the same year Wesson echoed Davis's remarks: "With the possible exception of operation for hydronephrosis or calculi, no renal surgery should be performed until the diagnosis has been confirmed by a retrograde urogram."214 In his 1946 monograph, "A Contribution to the Diagnostics of Nephromata," Johnson listed no fewer than forty-two authors on record as opposing excretory urography in renal tumor diagnosis.215

In brief, the facts suggest that for twenty years after the appearance of excretory urography urologists used it primarily when they wished to compare the "functions" of the kidneys or when ureteral catheterization was undesirable or impossible.216,217 Otherwise, when
important decisions were to be made the nod regularly went to retrograde pyelography.

Urography met a somewhat more friendly reception in Scandinavia than it did in the United States and most of Europe. Urography was much better accepted by urologists in Scandinavia and, indeed, appeared to be practiced on a higher technical plane than elsewhere. Johansson attributes this acceptance to the routine use of ureteral compression popularized by Hellmer in Scandinavia in 1935 but not practiced routinely elsewhere.218 Many urologists, influenced (paradoxically) by the strenuous objections of von Lichtenberg, rejected compression, primarily because, as the master put it, it was "unphysiological and destroys its primary purpose as a physiological test." Von Lichtenberg, as it turned out, never warmed to urography as a morphological study.219

Using the Scandinavian technique of urography, Johansson in 1946 was able to reduce the need for retrograde pyelography to a mere 13 percent of seventy-nine patients with renal cell carcinoma. In comparison, the American, Graham, writing in 1947, was compelled to resort to pyelography 66 percent of the time.220 The technique of compression appeared to be as important as the compression itself. The more efficient Scandinavian method made use of a girdlelike apparatus, which allowed the patient considerable mobility for oblique and other projections.222,228 This device did not become commercially available in the United States for many years.224,225 The American method, on those occasions when it was used, employed a table-based band which held a large balloon ("Hickey bag") against the abdomen and restricted the patient to the supine position.226 Ironically, one of the earliest references to ureteral compression during excretory urography was by the American urologist Woodruff, who commented favorably upon it in 1931, as did the radiologist Kornblum the following year in a state-of-the-art review of the as yet fledgling examination of excretory urography.227,228

To Lubash, however, should probably go the credit for first specifically directing attention to the value of ureteral compression, although it is certain that others, including Swick, knew about it and used it occasionally if not routinely.229,230 I. Seth Hirsch, a New York radiologist who himself used compression sparingly, stated that the Germans Ziegler and Kohler employed compression in association with the use of Roseno's compound, Pyelograph, which would suggest that the use of compression was older than Uroselectan itself. Colliez, one of the fathers of French uroradiology, also pioneered the use of ureteral compression at about the same time.231 Another urologist who found himself in the minority was Fritchard, who, like many urologists of his day, performed urography in his office.232 Unlike the others, however, he believed in relatively large doses of contrast medium (approximately 60 cc.) and found it necessary to do retrograde pyelograms in only 2 percent of his patients!

Urography Comes of Age

Nephrotomography and high-dose urography

Slowly but steadily, excretory urography improved in quality and acceptance. Although not formally named until 1932 by Wesson and Fullmer, the "nephrographic" effect or visualization of the renal parenchyma during urography had been known since its earliest days.233 Kornblum, however, thought Alexander Randall, professor of urology at the University of Pennsylvania Medical School, may have used this term before 1932.234 Randall, ahead of his time, was a strong believer in the benefits of friendly collaboration between urologists and radiologists and insisted that each know and respect his own limitations. Jaches in 1930, and later Wesson and Fullmer, described particularly intense nephograms during acute ureteral obstruction (obstructive nephrogram), and in 1938
Steinberg and Robb noted intense nephrograms during the performance of intravenous angiography. Helmer, chief of diagnostic radiology at the University of Lund, Sweden, reviewed the subject of nephrography in 1942 and concluded that cysts, because of their radiolucency, could usually be differentiated from tumors.

Five years later, Weens and Florence attempted to produce diagnostic nephrograms by obstructing ureters with balloon occluding ureteral catheters. Although the technique worked, it was both too cumbersome and too uncomfortable to gain clinical acceptance. Yet the diagnostic promise of nephrography prompted continuing efforts to refine it. Vesey, a radiologist, extended the earlier observations on nephrography with his own technique of bolus injection of 50 cc. of 75 percent Neo-Iopax followed by two abdominal films. Independently, Weens and his colleagues at Emory University in Atlanta hit upon the same scheme but added a rapid cassette changer. Both investigators claimed a high technical success rate (72 to 83 percent), but Vesey remained leery of making an unequivocal diagnosis of tumor by nephrography. Other contributors to bolus nephrography during this period were Leigh, Rogers, Wall, and Rose.

Although nephrography supplemented the urogram nicely, its clinical impact was marginal in view of the time and effort involved. Something better was needed. In 1942 Eugene Pendergrass, professor and chairman of the department of radiology at the University of Pennsylvania, while delivering the annual Carman Lecture at the meeting of the Radiological Society of North America (RSNA), spoke of enhancing nephrographic detail by means of tomography. He was not the first to suggest this or to perform it. Pendergrass was preceded by Jochims in 1939 and Bourne in 1941. But despite an occasional favorable report, renal tomography failed to gain wide popularity.

In 1954 John Evans and his associates gave both nephrography and tomography a new aura of respectability by combining the two into one study, nephrotomography (Fig. 9.24). Adding tomography to the Vesey method of nephrography enabled Evans to visualize the renal parenchyma with a level of detail heretofore unattained and to significantly improve the assessment of renal masses. Three years later, after having switched from a dose of 50 milliliters (ml.) of 50 percent Urokon to 50 ml. of 90 percent Hypaque, Evans reported an accuracy rate of 90 to 95 percent in differentiating benign from malignant renal lesions. Still, this technique remained too cumbersome for routine use, and, of greater concern, 11 percent of all renal carcinomas remained undetected. For nephrotomography to be enthusiastically embraced would require further technical improvements.

Although in the earliest days of excretory urography researchers often used doses of 100 ml. of 40 percent Uroselectan (17 grams of iodine), the volumes administered fell as the iodine content of contrast media increased. By the mid-1950s doses of 20 ml of 50 percent Neo-Iopax or Diodrast (with less than 5 grams of iodine) had become standard, and, with the exception of a few iconoclasts like Pritchard, most radiologists (and urologists) were reluctant to go higher. After Robb and Steinberg and, later, Weens showed that larger doses not only produced better studies but were well tolerated, some physicians began to question the need to adhere blindly to the time-honored 20 ml. regimen of a previous generation.

The value of large doses was vividly demonstrated by angiographers who
regularly noted extraordinarily well-opacified urinary tracts after contrast doses of 100 to 200 cc. for vascular studies. Large-dose urography first found favor in special situations such as renal insufficiency and the evaluation of infants and children with abdominal masses (total body opacification). Before long increasing-ly large volumes were being used routinely either as single or as repeat ("double-dose") injections. In 1964 high-dose urography was discussed in detail by Friedenberg and Carlin, whose report helped to further popularize the method.

The conversion to routine high-dosage urography was given its biggest boost by Shenckcr, who in 1963 introduced the drip-infusion technique, thereby greatly simplifying the process of delivering large volumes of contrast. This method (the credit for which Shenckcr gives to Winchell and Arata) consists of infusing between 150 and 300 ml. of a mixture composed of equal parts 50 percent Hypaque and 5 percent dextrose in water in six to ten minutes. When radiologists saw the superb urograms produced by this and other high-dose techniques, it became clear that they could never go back to traditional doses. Moreover, because infusion urography produced a persistently dense nephrogram as well as a well-opacified urinary tract, it seemed only natural to adapt it to nephrotomography. By administering the contrast medium as a drip infusion instead of a bolus, Shenckcr eliminated the need for 12-gauge trocars, precise timing of the film exposures, and several other annoying components of classical nephrotomography, making the procedure much more acceptable. It should be noted that, shortly before Shenckcr's first report, Whitesell and Heller described a slightly different technique of infusion urography in a scientific exhibit before the South Central Section of the AUA (October 1963). The obvious improvement in renal visualization provided by tomography soon led to its incorporation, like high iodine doses, into the routine excretory urogram.

As Evans pointed out in his twenty-year retrospective of the subject in 1974, the main contribution of nephrotomography was not so much in enabling radiologists to differentiate between renal cysts and neoplasms (Bosniak later showed that it took more than simple nephrotomography to do this), as it was in defining the quintessential ingredients of the intravenous urogram and in garnering new respect for the radiologists who were performing and interpreting uroradiological studies. The work of Evans and his associates helped to make both tomography and relatively large doses of iodine (i.e., 30 grams or more) requisite components of modern excretory urography. Whereas the development of tri-iodinated contrast media must rank as the most important event in the past fifty years of urography's evolution, nephrotomography surely was crucial in shaping its present image.

The heyday of urography

As excretory urography continued to improve, the voices of its critics grew fainter and some of its earlier faultfinders finally, if begrudgingly, came around. For example, David M. Davis, writing in 1959, said, "Intravenous urography is now a very important method of examination." The work of British uroradiologists in the 1960s, including Fry, Saxton, and Sherwood, as well as the Australian, Benness, helped to elucidate the physiological underpinnings of urography and placed it on a firm scientific basis. Saxton's monumental 1969 monograph, in particular, gave many radiologists a new appreciation of the study and raised their standards of performance. Lalii's emphasis on avoiding rigid protocols and "tailoring" urography to each patient's unique clinical requirements strengthened the need for radiological supervision of the study, while the 1974 National Uroradiological Conference sponsored by the American College of Radiology (ACR) codified the standards for optimal urography and reinforced the procedure as an indispensable part
of clinical medicine.267,268

For all practical purposes, the coming of age of excretory urography in the 1960s signaled the end of urologist-dominated uroradiology. Few urologists now had either the radiological training necessary to supervise the procedure or the desire to purchase the necessary equipment (e.g., high-output generators, tomographic apparatus). As urography improved, so too did the need for retrograde pyelography diminish. Critics of pyelography grew in number and became more strident. Studies dwindled and pyelography gradually became a pariah. At pyelography’s ebb, a radiology department’s uroradiological reputation was sometimes measured, in part, by how few retrograde studies it performed.269

By 1970 retrograde pyelography appeared to be a study whose time had gone. It had taken on the look of a radiological Edsel. Excretory urography had become the linchpin of uroradiological diagnosis, and uroradiology was now firmly in the hands of radiologists. The subsequent appearance of low-osmolar contrast media did little to alter the situation, although for reasons of cost as well as chemistry (higher iodine content) a trend toward slightly lower dosages with these agents became apparent. As is often the case with sovereignty, however, the crown did not rest securely on urography’s head for long.

The Lower Urinary Tract

Lower urinary tract radiology also experienced some interesting, if somewhat less exciting, developments during the urographic era. Langer’s 1981 monograph was a landmark as lower urinary tract radiology continued to draw the attention of European radiologists.270 But it was not until 1933, when the American urologist Reuben Flocks used a double contrast of air and Lipiodol jelly to demonstrate the urethral manifestations of both benign prostatic hyperplasia and prostatic carcinoma, that a comparable level of interest in cystourethrography was evoked in the United States.271 Meanwhile, Ortman and Christiansen advocated performing voiding urethrography after intravenous urography, thus avoiding instrumentation, while Knuusson championed the neon-lateral projection for urethrography.272,273 In 1941 Brody described a new clamp for urethrography which became very popular with urologists, while radiologists seemed to prefer occluding the distal urethra with the balloon of a Foley catheter slightly inflated in the fossa navicularis.274 Edlings’s 1945 thesis on micturition studies did much to establish near parity between the voiding and retrograde modalities, but the main investigational spotlight still remained directed on retrograde urethrography.275 Focus in the 1940s was on more viscous water-soluble contrast media for urethral instillation. Agents such as Visco-Rayopaque (Diodrast in 4 percent polyvinyl alcohol), Ulmbadil-Viscous U (Diodrast in carboxymethylcellulose), and Thixokon (Urokon in cornstarch) were introduced with fanfare but were never well received.276,277,278 Largely due to the work of Kjellberg and his associates, and later that of Shopfner, a new awareness of the role of voiding urethrography, especially in children, took hold as voiding studies began to throw fresh light on the physiology of micturition while dispelling many older notions about the etiology of lower urinary tract disorders.279,280 This flurry of activity dovetailed when Ramsey, Watson, and Benjamin, working at the University of
Rochester, developed and applied the techniques of cinefluorography and cineradiography to the study of vesico-urethral pathophysiology; concurrently, somewhat similar equipment was being used by Hinman, Miller, and their associates in San Francisco to found the new discipline of urodynamics (Fig. 9.25).281,282 While Boeminghaus mentioned cinematography during voiding as early as 1921, and South American radiologists Pachecho and de Costa were the first to perform the procedure, the work of both Benjamin's and Hinman's groups constituted a significant first for radiology and marked a new era in the intermarriage of radiology and physiology.283,284 Cine studies became very popular in the 1950s and early 1960s, but their high exposure dosages eventually led to their replacement by fluoroscopic spot films, cameras, and videotapes in lower urinary tract evaluation.

Retrorgrade urethrography in females generated relatively little attention, partly due to the technical difficulty in occluding both ends of the female urethra and partly due to the effectiveness of voiding urethrography in visualizing the female urethra. Davis and Gian developed a double-balloon catheter for retrograde urethrography in women, but it is used only rarely, if at all, by most radiologists.285 A flexible, linked bead chain, designed to radiographically outline the course of the urethra and bladder neck in women with stress incontinence, was inserted into the urethra by Hodgkinson, Doub, and Kelly in 1958, but their technique of chain cystourethrography, although initially received enthusiastically, has waned in popularity.286

Retroperitoneal Pneumography

Two imaging modalities which appeared in the 1920s, retroperitoneal pneumography and angiography, had diametrically opposite fates. Retroperitoneal pneumography, introduced almost simultaneously in 1921 by Rosenstein of Berlin, who used oxygen, and Carelli and Sordelli of Buenos Aires, who used mainly carbon dioxide, was an outgrowth of pneumoperitoneography first introduced in 1914 by Rautenberg.287,288,289 These early workers, using a translumbar route, made their needle punctures directly into the perinephric space. They were impressed with the clarity with which the gas-encased renal outlines could be discerned, but occasional reports of gas embolism were disconcerting. Modifications of the technique to provide a less vascular needle pathway were suggested in 1948 by Ruiz-Rivas, who inserted the needle pre-sacraly, and by Vogler in 1952, who advocated a para-coccygeal approach, with a resultant decrease in the frequency of embolic complications.290,291

In spite of the improved renal visualization obtained with retroperitoneal pneumography, especially when it was combined with excretory urography and aortography, the technique never gained more than limited acceptance (Fig. 9.25).292 The one area in which it achieved the most support was in demonstrating adrenal masses. Cahill, who was the first to appreciate its value in visualizing these lesions, and Gianturco became its strongest proponents in the 1930s.293,294 Nevertheless, the use of retroperitoneal pneumography declined precipitously as newer, improved techniques for urography found their way into the radiological community. With the advent of higher doses of contrast media and routine tomography, its disappearance was complete.

Angiography

Angiography, on the other hand, was to have a major impact on uroradiology. Although arteriography had been performed successfully, if sporadically, prior to dos Santos's pioneering work in 1925, no one had succeeded in visualizing the renal circulation in humans prior to this Portuguese surgeon's brilliant discovery of translumbar aortography.295 However, the reception given to this new technique was cool and, save for arguments about the safety of the procedure, dos Santos and his work were largely ignored for many years.296 Although dos Santos
Fig. 9.26 Retroperitoneal pneumogram of the right kidney taken from Rosenstein's first paper (1921). (Author's collection)

angiography were being developed. Ichikawa in 1958, Farinas in 1941, and Goodwin in 1950 catheterized the femoral artery (or its branches) through a cutdown and passed a ureteral catheter to the abdominal aorta. While the site of contrast deposition could be better controlled with this transfemoral approach, the need for arteriotomy and an operating room environment kept the procedure from broad acceptance. In 1951 Pierce took arteriography a step further when he devised a percutaneous approach to the femoral artery using a 12-gauge needle through which polyethylene tubing was inserted to the desired level in the aorta. Pierce's technique had one major drawback, however; the mismatch in caliber between the relatively large needle and the narrow plastic catheter provided no tamponade and led to troublesome, sometimes serious, bleeding around the puncture site upon removal of the needle. Thus, before 1953, translumbar aortography, technically altered little if at all from dos Santos's original description, was still the procedure of choice for visualizing the renal arteries, even though critics were quite clear about it being an overutilized and perhaps overvalued technique. Seldinger's discovery in 1953, though, changed everything.

Sven Seldinger's ingenious description of a needle-guide-wire-catheter technique was not only brilliant but it revolutionized all of radiology. (Ironically, Seldinger was unable to introduce his epochal discovery on schedule. He could not obtain permission to travel to Helsinki where, perforce, his paper was read by title only at the June 1952 Congress of the Northern Association of Medical Radiologists. Another example of genius unappreciated.) It was followed in short order by many advances in catheter design leading to selective arteriography. Odman produced radiopaque catheters in 1955, while in 1956 both he

Dr. Vincent O'Connor [Chicago urologist] to dos Santos: "Do you use this procedure on private patients as well as on the service cases?"

Dr. Reynaldo dos Santos (laughingly): "I do aortography only on Spaniards, not on Portuguese."

Meanwhile, alternative techniques for first demonstrated the classical hypertensive pattern of renal cell carcinoma and presented in exquisite detail the unique contributions of aortography in renovascular disease, congenital anomalies, and preoperative vascular mapping; clinicians were reluctant to adopt translumbar aortography, probably because of the concept of blind puncture of the aorta was daunting and no doubt also because of fear of complications related to the use of sodium iodide as the contrast agent. The introduction of safer water soluble contrast media improved things a bit, but, were it not for the steadfast support of a few urologists like Nelson, Doss, and Smith, the method would have fallen into total disuse.

Dos Santos felt this rejection keenly, of course, but was usually able to maintain a pragmatic and sometimes humorous perspective:

Pollack
and the team of Edholm and Seldinger independently described curved-tip catheters specifically for entering the renal artery.\textsuperscript{311,312,313} Thus selective renal arteriography was born and with it a new era in uroradiological diagnosis. It would be difficult to overemphasize the full impact of angiography on the management of genitourinary diseases. Not only was the differentiation of renal tumors from renal cysts now possible with a new-found accuracy of 75 to 95 percent, but as selective angiography (now enhanced by subtraction and magnification techniques and the use of epinephrine) found increasingly broad applications in a variety of renal diseases including vascular, inflammatory, cystic, congenital, and traumatic, it took the diagnosis of surgical renal disease to a new level of precision.\textsuperscript{314} It was no longer necessary, for example, to operate on all renal masses to ensure that a neoplasm was not present.

Perhaps the most significant changes wrought by renal angiography lay outside of diagnosis. Because of the technical and interpretive skills required for its performance, the extraordinarily detailed anatomy revealed, and the formidable array of dazzling new equipment, angiography garnered new respect and admiration for radiology and radiologists. The emergence of selective renal angiography, more than any other single factor, was responsible for finally transferring the responsibility for urological radiology from urologists to radiologists.

Venacavography to demonstrate tumor thrombus from renal cell carcinoma was carried out first by O'Loughlin in 1947 and repeated by Duff and Granger four years later.\textsuperscript{315,316} Gidlund appears to have been the first to inject the catheterized renal vein with contrast in 1950,\textsuperscript{317} Pearson and Sutton reported a similar technique in 1958, while Helander and Lindbom opacified the renal veins by means of a Valsalva maneuver during contrast injection into the inferior vena cava.\textsuperscript{318,319} The modern technique of renal vein opacification following temporary arrest of flow in the renal vasculature originated with Gilliot's experiments on balloon occlusion of the inferior vena cava, followed later by Olin and Reuter's observations that renal arterial flow could beD

\textbf{POST-UGROPHIC ERA (1975–1995)}

The golden age of urography reached its zenith in the years 1970 to 1975. However, with the arrival of new imaging modalities, such as radionuclide imaging, ultrasound, and computed axial tomography (CT), providing information which urography could never impart, urography's domination of urological imaging began a slow but inexorable decline.

\textbf{Urological applications of radionuclides}

The first competitor on the scene was nuclear medicine. The earliest attempts to study the kidney with radionuclides date to 1952, but nuclear medicine made no significant impact on clinical renal imaging until the 1970s. Chester Winter and George Taplin are traditionally credited with having first wedded radioisotopes to the urinary tract when in 1955 they described the radiorenogram (Fig. 9.27).\textsuperscript{320} In fact, they were preceded in their efforts by Oeser and Billion, who in 1952 studied the renal excretion of $^{131}$I Uroselectan by plotting tracings from collected urine samples.\textsuperscript{321} Even Winter and Taplin's priority as the discoverers of renography has been debated, since there is a question as to whether Kimbel and his associates from Germany may have actually pioneered the technique.\textsuperscript{322,323} However, Winter and Taplin clearly deserve credit for having popularized and exhaustively investigated the numerous clinical applications of renography and, with Nordyke and Tubis, for having introduced $^{131}$I sodium orthoidodhippurate (Hippuran) for renography and renal function studies.\textsuperscript{324} There is also reason to believe that Winter, in association with Willard Goodwin, may have been the first to attempt renal scintiscans. They employed $^{131}$I Diodrast but were
unsuccessful because of the long scanning times of their crude detection system compared to the relatively short excretion time of Diodrast. Winter was, however, able to obtain some renal scans in rabbits by obstructing the ureter and prolonging the excretion time of the radionuclide.\textsuperscript{297}

Since early work with radioisotopes in the urinary tract was more functionally oriented than morphological, it constituted no threat to urography as a clinical imaging tool. This changed, however, with the advent of the gamma camera, computers, and technetium \textsuperscript{99m}Tc-labeled compounds. A harbinger of things to come was provided by McAfee and Wagner who, using a rectilinear scanner and the radionuclide Hg\textsuperscript{197} chlormerodrin, performed the first renal scintiscans in 1960.\textsuperscript{298} In so doing they introduced a radically new method of visualizing functioning renal parenchyma, long a serious and annoying deficiency of urography. Although the later appearance of Hg\textsuperscript{197} chlormerodrin lowered the radiation dose to the kidneys and improved the images, clinically reliable renal parenchymal imaging was still a few years off.\textsuperscript{299} The real breakthrough came in 1966 when Powell and Anger, as well as Rosenthal, presented the results of their work on renal perfusion imaging with the new, faster gamma camera.\textsuperscript{300,331} When \textsuperscript{99m}Tc dimethylentetramine pentaacetic acid (\textsuperscript{99m}TcDTPA) made its appearance in 1970, the modern era in radionuclide renal imaging had arrived.\textsuperscript{302} Subsequent technical advances in the form of single photon emission CT (SPECT), positron emission tomography (PET), and the development of isotopes such as \textsuperscript{99m}Tc mercaptoprotaetlyltriglycine (\textsuperscript{99m}TcMAG3) promise even more detailed anatomical and physiological imaging in the future.\textsuperscript{303,304,315} A historical chronology of some of the above events and selected additions is seen in Table 9.1.

While radionuclide imaging does not provide as detailed a view of the finer intrarenal structures as does urography, it does depict the renal parenchyma far better than the older study, and at the same time it yields a unique functional-related image. Its limited spatial resolution has, thus far, prevented radionuclide imaging from supplanting urography as a first level urological imaging modality in most clinical scenarios, but it has begun to chip away at it. It has, for example, become an integral part of imaging the transplanted kidney, as well as evaluating patients with suspected renal hypertension. It is also gaining increasing favor in renal imaging of infants and children, in pyelonephritis, in following vesicoureteral reflux, in some cases of suspected extravasation, in the patient with acute scrotal pain, and in those with equivocal obstructive uropathy.

**Ultrasonography**

Although it is difficult today to conceive of the practice of uroradiology without ultrasound, the assimilation of ultrasonography into urinary tract imaging was a slow, protracted process. Perhaps the depiction of anatomy as a series of dots was so far afield from what most radiologists were accustomed to viewing that they resisted incorporating sonography into their practices for long periods of time. In fact in the early days of
ultrasound the interpretation of sono-
grams proved an anathema to many 
radiologists, while others refused to 
even take it seriously.

The first recorded applications of 
diagnostic sonography to the genitouri-
mary system of patients date to the very 
earliest days of ultrasound when, fol-
lowing on the heels of Ludwig's seminal 
observations on A-mode pulsed echo 
reflections, Wild and Reid in 1952 pub-
lished an image of a kidney.345,344

Three years later these same pioneers 
developed a rotating endorectal scan-
er which enabled them to record reflected echoes from the rectal wall and underlying tissues.345 Although 
they attempted to obtain images of the 
prostate, their A-mode equipment was 
so primitive and their images so poor 
they were discouraged from reporting 
them.346 Following up on Wild's idea, 
Takahashi and Ouchi were able to 
record A-mode reflections from the 
prostate by the transrectal route in 1963 
and even obtained crude cross-sectional 
images a year later.347,348 But it was 
not until 1967, when Watanabe, looking 
for an electronic stethoscope with 
which he could "listen to the urinary 
stream from the rectum," stumbled 
av transesophageal ultrasound 
transducer in a cardiology laboratory 
and was immediately compelled to try it 
out on the prostate, that the first clin-
ically useful transrectal sonograms of 
the prostate were obtained.349

At about the same time Wild and 
Reid were conducting their investiga-
tions, a group at the University of 
Colorado headed by Joseph Holmes and 
Doug Howry were experimenting with 
cross-sectional abdominal imaging. In 
1952 Howry, aided by W. Roderic Bliss, 
an engineer, had produced the first 
abdominal cross-sectional sonograms 
(Fig. 9.28).350 As a nephrologist, Holmes 
was primarily interested in obtaining 
renal sonograms, which he and Howry 
accomplished in the mid-1950s.351 Using 
an excised kidney suspended in a water 
bath, this pair demonstrated the typical 
sonographic appearance of a renal cyst.

Soon after, in 1963, Holmes, whose 
name would become synonymous with 
card urological sonography, reported 
the first sonograms of the normal urin-
ary bladder, of polycystic kidneys, and

Table 9.1

<table>
<thead>
<tr>
<th>YEAR</th>
<th>EVENT</th>
<th>INVESTIGATOR</th>
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<tbody>
<tr>
<td>1952</td>
<td>Counted urine after excretion of $^{131}$I Uroselectan</td>
<td>Oser and Bilton</td>
</tr>
<tr>
<td>1955</td>
<td>Radioleneography with $^{131}$I Uroselectan</td>
<td>Taplin, Winter, et al.</td>
</tr>
<tr>
<td>1956</td>
<td>Radioleneography with $^{131}$I Diodrast</td>
<td>Kimbel et al.</td>
</tr>
<tr>
<td>1960</td>
<td>Development of $^{131}$H Hippuran and measurement of renal plasma flow</td>
<td>Winter, Nordyke, and Tubbs</td>
</tr>
<tr>
<td>1960</td>
<td>Renal scintigraphy with $^{203}$Hg chloromerodrin</td>
<td>McAfee and Wagner</td>
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<tr>
<td>1963</td>
<td>Compartmental analysis of renogram curve</td>
<td>Blaufax et al.</td>
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<tr>
<td>1963</td>
<td>Hg$^{131}$H chloride</td>
<td>Sodee</td>
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<td>1964</td>
<td>Vesico-ureteral reflux</td>
<td>Berne and Eckman</td>
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<td>1966</td>
<td>$^{99m}$TcU perfusion scanning</td>
<td>Powell and Anger</td>
</tr>
<tr>
<td>1968</td>
<td>Deconvolutional analysis of renogram</td>
<td>Rosenthal</td>
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<td>1968</td>
<td>Diuretic renography</td>
<td>Britton and Brown</td>
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<tr>
<td>1969</td>
<td>$^{99m}$TCI glucenate scanning</td>
<td>Rode et al.</td>
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<tr>
<td>1970</td>
<td>Split renal function</td>
<td>Charanza and Budikova</td>
</tr>
<tr>
<td>1984</td>
<td>Caprotul renography</td>
<td>Hauser</td>
</tr>
<tr>
<td>1986</td>
<td>$^{99m}$TcMAG$_3$</td>
<td>Schlegal and Hamway</td>
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<tr>
<td>1986</td>
<td>SPECT</td>
<td>Ole et al.</td>
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<tr>
<td>1990</td>
<td>Renal PET</td>
<td>Fritzberg et al.</td>
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Wahl et al. |
of renal calculi in the intact kidney (Fig. 9.29).\textsuperscript{352} In 1961 Schlegal adapted the ultrasonic flaw detector for use in locating hard-to-find kidney stones during nephrolithotomy.\textsuperscript{363}

One of the earliest publications to produce a serious clinical impact on urological diagnosis was that of Goldberg and his associates in Philadelphia in 1968. Using A-mode sonography, they showed that they could distinguish renal cysts from solid or complex renal masses with 95 percent accuracy (Fig. 9.30).\textsuperscript{364} This represented a major breakthrough in a very perplexing diagnostic area which theretofore had not fully succumbed to either angiography or the technically demanding procedure of nephrotomography. An expanded version of this work was presented and enthusiastically received at the 66th annual meeting of the AUA in Philadelphia in May 1970, in what appears to have been one of the first papers on sonography ever presented before a national urological meeting.\textsuperscript{365} Shortly thereafter, Schreck and Holmes were able to produce results of comparable accuracy using two-dimensional sector scanning.\textsuperscript{366} It was not until twelve years later, however, that a controlled, prospective study of a large group of patients finally provided the necessary statistical proof that sonography could indeed be relied upon to sort out renal cysts from other renal masses with the extraordinary degree of accuracy which had earlier been claimed for it.\textsuperscript{367} In so doing, it literally put an end to the need for diagnostic aspiration of renal cysts (see later).
In 1968 Nishi, in Gifu, Japan, made the first attempts to obtain transurethral sonograms from within the urinary bladder and urethra, but he had access only to A-mode equipment and his results were of limited value. Six years later Holm and his group in Copenhagen obtained two-dimensional sonograms of the prostate and bladder wall using a more modern transurethral probe. They felt that staging of bladder cancer was more reliably accomplished in this manner than by abdominal scanning. Another major breakthrough came in 1969 when Sampson in London applied Doppler techniques to the kidney for the first time and showed reduced blood flow to a rejecting renal allograft. Doppler sonography was also pursued aggressively by Japanese investigators, who in 1976 first reported detecting signals from renal vessels in vivo.

Diagnostic ultrasound took on a new perspective in the late 1960s and early 1970s when several investigators, including Goldberg and Pollack in Philadelphia, Holm and his associates in Copenhagen, and Kroadewill in Vienna, independently learned how to drill a central channel through an ultrasonic crystal without flawing its acoustical properties and thus developed the A-mode aspiration/biopsy transducer (Fig. 9.31). The technology soon was applied to B-scan equipment, and, eventually, a modification of the concept was made available for real-time transducers, making it possible to insert and direct needles accurately to any structure lending itself to sonographic visualization. The sonographic method of needle placement presented a swift, safe, and effective means of performing aspiration, biopsy, and drainage procedures and helped to spawn renewed interest in procedures such as renal cyst aspiration, antegrade pyelography, renal biopsy, and biopsy of renal and other masses.

Percutaneous nephrostomy in particular benefited by the development of interventional ultrasound, as Pederson in 1974 first showed how it could be used to facilitate this procedure. Later, Zegel and his associates proved that sonographic localization of the kidney for puncture resulted in less needle sticks and a shorter operating time than fluoroscopic localization. The development of transrectal biopsy of the prostate was also based on the same principles of sonographic needle guidance. Ultrasound served as the primary guide for inserting needles into the urinary tract until the mid-1980s, when it was supplanted to a great extent by CT for abdominal procedures. Nonetheless, ultrasound still retains an important place in many interventional urinary tract studies.

Before the advent of ultrasound, scrotal structures were notoriously difficult to evaluate, with nuclear imaging representing the only helpful study. Miskin and Baim in 1974 made the first application of sonography to the scrotum and showed sonographic abnormalities in a variety of conditions. Three years later the same authors, now employing gray scale methodology, were able to improve and expand upon their original observations and correctly predict the important impact scrotal sonography would eventually have. The first application of Doppler ultra-
sound to the assessment of testicular blood flow was by Millereit and Liaras, who in 1974 correctly diagnosed testicular torsion by this method. 374

As contact scanning replaced the water bath, as the development of real-time imaging replaced static bistable images, and as the invention of the scan converter led to gray scale capability, urinary tract sonography became increasingly sophisticated and the images more and more equatable with traditional concepts of anatomy. 375,376,377 Gradually clinicians grew more comfortable with sonography and eventually accepted it on an equal footing with the older radiographic studies of the urinary tract. Today, with the availability of color-flow Doppler and computerization of scanners, urosonography has carved out its own indispensable niche in uroradiology, where it currently enjoys primacy in such areas as screening the azotemic patient; assessing abdominal masses in infants and children; detecting hydronephrosis; renal surveillance in patients at risk for Wilms' tumor and polycystic disease; evaluating for certain types of urinary tract calculi; monitoring the progress of fluid collections (e.g., hematomas); scrotal evaluation; localization for biopsy and other procedures on the kidney and prostate; localization for interventional procedures on the bladder and kidneys, including percutaneous nephrostomy; aspiration and drainage of cysts, abscesses, etc.; evaluating the progress of stone disintegration during lithotripsy; and, of course, the original and still irreplaceable function of differentiating solid from cystic structures. 378

The recent introduction of color-coded Doppler sonography has further enhanced ultrasound's role in renal vascular diseases and the evaluation of male sexual dysfunction. Endoluminal ultrasound carries the promise of imaging the ureter and renal collecting system from an entirely new perspective, while ultrasonic contrast agents bid well to significantly expand ultrasound's diagnostic range. 379

Paradoxically, those virtues of low cost, portability, and ease and speed of operation which make ultrasound so attractive to radiologists have not missed the eye of other practitioners. The expropriation of sonography by genitourinary surgeons who lately have discovered its virtues has produced so-called "turf" squabbles over urological imaging as controversial as any seen since the 1940s and 1950s, especially with regard to transrectal sonography and sonographic monitoring of extra-corporeal lithotripsy. Nonetheless, the ever-increasing complexity and cost of ultrasonic equipment will probably eventually produce an equilibrium in urosonographic activities, with urologists continuing to perform office-based, less-expensive procedures and hospital or imaging center-based radiologists responsible for studies performed with higher priced equipment. Hovering in the background of such conjecture, however, are the changing patterns of health care delivery now sweeping over American medicine. These changes, already making an impact on diagnostic imaging, could determine to a great extent where and by whom such studies are done and render moot most questions of jurisdiction. A chronology of the watershed developments in urosonography are listed in Table 9.1.

Computed Tomography

Unlike sonography's incremental influence on uroradiology, CT had an immediate and profound impact. From the outset clinicians were more comfortable with CT than with ultrasound. The exquisite morphological renderings provided by this revolutionary new technique made anatomico-pathological correlations much clearer than with other imaging techniques. Hence CT was immediately and enthusiastically assimilated into clinical practice (sometimes before there had even been an adequate opportunity to evaluate its effectiveness). The effect on uroradiology was as dramatic and far reaching as that produced by any development since the discovery of excretory urography and, it may be seriously argued, even earlier than that—perhaps as far back as the
<table>
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<th>YEAR</th>
<th>EVENT</th>
<th>INVESTIGATOR</th>
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<tbody>
<tr>
<td>1947</td>
<td>Pulsed echo A-mode</td>
<td>Ludwig⁵⁴⁹</td>
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<tr>
<td>1952</td>
<td>Compound cross-sectional imaging</td>
<td>Howry and Bliss⁵⁵⁰</td>
</tr>
<tr>
<td>1955</td>
<td>Transrectal ultrasound</td>
<td>Wild and Reid⁵⁵¹</td>
</tr>
<tr>
<td>1958</td>
<td>Direct contact scanning</td>
<td>Takahashi 1962³³³</td>
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<tr>
<td>1960</td>
<td>Scans of urinary bladder</td>
<td>Watanabe 1968³⁴⁹</td>
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<tr>
<td>1961</td>
<td>Demonstration of renal calculi (intraoperative)</td>
<td>Donald and Brown³⁶⁵</td>
</tr>
<tr>
<td>1963</td>
<td>Scans of polycystic kidneys</td>
<td>Olives³⁵¹</td>
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<tr>
<td>1968</td>
<td>Real-time scanning</td>
<td>Somer³⁶⁶</td>
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<tr>
<td>1968</td>
<td>Differentiation of renal masses</td>
<td>Goldberg et al.³⁵⁴</td>
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<tr>
<td>1968</td>
<td>Transurethral scanning</td>
<td>Nishi³⁵⁸</td>
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<tr>
<td>1969</td>
<td>Doppler ultrasound of kidney</td>
<td>Holm et al. (1979)³⁵⁹</td>
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<tr>
<td>1970</td>
<td>Aspiration/biopsy transducer</td>
<td>Simpson³⁶⁶</td>
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<tr>
<td>1970</td>
<td>Interventional ultrasound</td>
<td>Goldberg/Pollack³⁶²</td>
</tr>
<tr>
<td>1972</td>
<td>Scan converter (gray scale imaging)</td>
<td>Kratchowill³⁶⁶</td>
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<tr>
<td>1974</td>
<td>Demonstration of renal calculi (intact kidney)</td>
<td>Holm et al.³⁶³</td>
</tr>
<tr>
<td>1974</td>
<td>Scrotal sonography</td>
<td>Pollack/Goldberg³⁶⁵</td>
</tr>
<tr>
<td>1975</td>
<td>Color Doppler</td>
<td>Klein⁶⁶⁶</td>
</tr>
<tr>
<td>1982</td>
<td>Efficacy assessment: renal cysts vs. renal tumors</td>
<td>Kohler⁶⁶⁶</td>
</tr>
<tr>
<td>1990</td>
<td>Endoluminal sonography</td>
<td>Goldberg et al.³⁶⁵</td>
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A landmark event in the field of urosonography was the introduction of retrograde pyelography in 1906.

Even before body scanners became available in late 1974 and early 1975, the kidney had already been examined by CT. Using an EMU CT 1000 first generation head scanner, Pickering and his colleagues at the Mayo Clinic reported on the CT appearance of the excised kidney in 1974 and recognized differences in the appearance of renal cysts and renal tumors.³⁵⁰ One year later Alfidi and associates at the Cleveland Clinic confirmed these early observations when they published the first experiences with in vivo renal imaging using an Ohio Nuclear body scanner.³⁵¹

Shortly thereafter reports of large series of patients studied with CT for abdominal diseases, including renal and adrenal disorders, began to appear.³⁵²,³⁵³ Sagel’s paper included the first recorded description of the CT diagnosis of renal angiomyolipoma, virtually eliminating one of the more perplexing problems in the differential diagnosis of renal masses.

Among the flurry of original contributions dealing with CT of the urinary tract which, for nearly a decade, seemed to increase exponentially each year, several have achieved special importance. Struyven and his colleagues in 1977 and Magilner and
Ostrum in 1978 were enthusiastic about the apparent ease with which renal cell carcinoma could be recognized with this new modality. The 1979 report by McClellan and his co-workers from the Mallinckrodt Institute of Radiology in St. Louis showed that CT, like ultrasound, could reliably differentiate renal cysts from other renal lesions, giving radiologists a second powerful weapon in the diagnostic war on renal masses. Only three years later Weyman and his colleagues suggested that CT could supplant angiography as the diagnostic standard for the recognition of renal cell carcinomas. In fact, it soon did. The superiority of CT for staging renal cancer was convincingly demonstrated by Johnson and his associates in a review of one hundred cases of hypernephroma.

In one of the earliest reviews of renal CT, Sagel and the group from St. Louis in 1977 described what was then known about the subject. Among other things, they pointed out the usefulness of CT in establishing the etiology of renal failure and the ease with which renal calculi could be seen. At almost the same time, Struyven and co-workers described the CT appearance of renal abscesses, and Haaga and Alfidi described the use of CT as an aid to needle biopsy or drainage—the first big step in what was to become an important new interventional technique—as well as a localization aid to performing both percutaneous nephrostomy and antegrade pyelography. CT was applied to the study of renal physiology by Brennan, Curtis, and Pollack. In a series of animal experiments these workers investigated the dynamics of cortical and medullary perfusion, the effect of contrast media cations and osmolality on medullary and urinary iodine concentration, and the relationship between urinary iodine concentration and CT attenuation (Hounsfield units). CT proved extremely valuable in unraveling the longstanding diagnostic problem of complicated renal cysts. Bosniak's grouping of these lesions into four categories based on their CT appearances was a logical extension of previous sonographically-based classifications, but the added information provided by CT gave this classification a precision ultrasound-based categories lacked and gained for it considerable reliance as a factor in the clinical management of difficult cases.

Among the first to apply CT to the assessment of pelvic urological disease were Seidelman and his associates in Cleveland who, in 1977, described the appearance and staging of bladder cancer using intravesical instillations of gas. The Cleveland group also described the appearance of the normal seminal vesicles and their alterations in advanced bladder cancer. Sukov, Scardino, and Sample appear to have first described in 1977 the contribution of CT to the evaluation of prostate carcinoma.

Because of the unique information provided by CT it soon became a powerful and essential tool for evaluating patients with diseases involving almost the entire spectrum of urological pathology. In many cases the information it provided necessitated a reevaluation of traditional concepts of disease, while its utility gradually led to the elimination of the need for several other diagnostic procedures such as angiography and lymphography. By the mid-1980s CT, while not yet the most commonly employed uroradiological modality, had become the most important one. Few major urological operations were undertaken without it, and urologists and radiologists alike came to depend upon it for the answers to difficult urological problems. Newer advances, such as spiral and ultra-fast scanning have only served to reinforce CT’s indispensable position in uroradiology. At first it appeared as though sonography would become a casualty of CT’s sudden popularity. The initial furor over CT did, in fact, stunt the growth of urological sonography, but this did not last long. In a few years, stoked by technological advances and the first stirrings of the public’s medical cost-consciousness, ultrasound resumed and even exceeded its former pace. Urography, however, did not fare as
well. Its utilization continued to decline as it had since 1975.

Magnetic Resonance Imaging

The emergence of magnetic resonance (MR) imaging techniques in the 1980s presented a powerful new tool for the evaluation of urological patients. As this chapter is written it is still too early to assess the full impact of MR imaging on uroradiology, but it is clear that it has already made significant inroads on imaging of the prostate gland and, with the aid of paramagnetic contrast media, appears poised to raise renal imaging, including the assessment of complex masses and certain medical (parenchymal) diseases to a new level of precision. The modalities which appear to lie directly in MR's line of fire include CT and angiography, but it is impossible to predict with any certainty how the various components of urological imaging will eventually sort themselves out.

Although nuclear MR was used to study the kidney as early as 1977, the earliest attempts involved spectroscopy only. By 1978 Mansfield and his colleagues at Nottingham had produced the first crude line scan MR images of the abdomen, including the kidneys, in a normal volunteer. In 1980 slightly more detailed MR images of the kidney were obtained in the rat by Hanson and his associates at the University of California at San Francisco (UCSF). These were followed shortly by images obtained in both animals and humans by several other groups both in the United States and in Great Britain. Although the early images were obtained with low field strength machines and would be considered primitive by today's standards, Young and associates at Hammersmith were able to recognize cortico-medullary differentiation in the normal kidney and its obscuration in chronic renal disease, while Smith and the group at Aberdeen by 1980 were able to differentiate some renal neoplasms from renal cysts with MR and recognize chronic suppuration. Some of the earliest laboratory investigations in animals were carried out by Newhouse and his co-workers (acute renal vein occlusion); London et al. (renal artery occlusion, hydronephrosis); Thickman and associates (acute and chronic ureteral obstruction); and Yuasa and Kudel, who evaluated MR changes produced by renal vascular occlusion in the rabbit. The first MR contrast agent employed for renal studies was a paramagnetic nitroxide, N-succinyl-N-4-amino-2,2,6,6-tetramethylpiperidine-1-oxyl (TES) developed by Brach and his colleagues at UCSF in 1983. The earliest work with gadolinium-DTPA as a renal agent came shortly thereafter, as several groups of investigators showed how the ready depiction of this compound's renal excretion pattern by MR made it an ideal contrast medium for the kidney. Pettigrew and colleagues suggested that curves of renal signal intensity might be used to measure renal function. Two reviews published in the early 1980s summarized the existing body of knowledge pertaining to MR of the kidney and urinary tract.

At about the time that radiologists decided they no longer wanted the term "nuclear" to be used in association with "magnetic resonance," the early low field strength imaging devices began to give way to mid-field strength equipment leading to considerable improvement in image quality. Particularly active at this time were Hedvig Hricak and her associates in the department of radiology at UCSF, who made many of the early and most significant contributions to urinary tract MR imaging. Bryan and his group in Cleveland, as well as the UCSF investigators, were pioneers in pelvic MR, including assessment of prostatic and vesical disorders. Core and co-workers appear to have been the first to have imaged the external genitalia. The unique value of MR in the recognition of various renal parenchymal diseases, especially those associated with the accumulation of hemoglobin and its metabolites, was demonstrated by several observers who studied patients with hemoglobinuria, sickle cell renal disease, and Hanta virus-related nephropathy.
By 1985 high-field strength imaging equipment was beginning to appear and was quickly applied to urological imaging. Using rapid sequence gradient recalled images Choyke and his associates at the National Institutes of Health tracked the renal transport of gadolinium-DTPA through the renal cortex and medulla and suggested that such dynamic techniques might prove helpful in the study of renal parenchymal disease. With the combined use of gadolinium-DTPA, surface coils, smaller fields of view, and faster, more innovative pulse sequences, the kidney, as well as other genitourinary tract structures, came under increasing scrutiny as the anatomical and pathological information provided by MR images became progressively more detailed. Nowhere was this more apparent than in the prostate gland, where the need to know more about this most common malignancy of males drove the technology to new levels.

Using a 0.04 Tesla unit, Steyn and Smith in 1982 were the first to image the prostate by means of MR. Although their images lacked the clarity of modern studies, the authors were able to distinguish benign prostatic hyperplasia from carcinoma correctly in nineteen of twenty-five patients having either of the two diseases. In 1985 Poon and his group from Toronto, using a 0.15 Tesla unit, improved on the image quality, but not on the diagnostic accuracy. Subsequently, images produced with 1.5 Tesla units changed the picture drastically, as intimate portrayals of the internal architecture of the prostate became possible and forced a reevaluation of earlier beliefs about prostatic anatomy and pathology. The need for more accurate staging of prostate cancer led to the development of an endorectal surface coil, later perfected and modified by the University of Pennsylvania group for use in a wide variety of pelvic disorders.

While in some anatomical areas MR has pushed CT into the background, this is not yet the case in the urinary tract. Perhaps as costs diminish and availability improves, MR will become dominant; it behooves crepe-hangers, however, to recall the earlier, dire, and utterly erroneous predictions that ultrasound would be rendered obsolete by CT.

Percutaneous Intervention

The origins of percutaneous interventions on the urinary tract are buried in antiquity, but clearly antedate the discovery of the X ray. As early as 1686 Tolet inserted cannulas through the perineum to relieve urinary retention from an impassable urethral stricture. Many other surgeons adopted similar or modified versions of the same technique. Riolan employed a suprapubic approach to the bladder, while Heister, in 1770, left a suprapubic cannula in place permanently in men suffering from bladder outlet obstruction.

Percutaneous procedures on the kidney probably had their beginning in the unroofing of bulging perinephric abscesses by pre-Renaissance physicians. In the latter half of the tenth century the Arab physician Serapion is said to have thrust a red hot irons through the flank and extracted a renal calculus. Almost as good is the story told of Hobson, the British consul at Venice in the mid-seventeenth century, who, following surgery for renal colic, continued to pass urine through a fistulous track in his flank until one day his wife, using a bodkin for a probe, extracted a date-shaped calculus from the tract, after which the man had no more symptoms. As related by Wickham and Miller, the man felt so well afterward that he was “able to perform the functions of life and to undergo fatigue as any man of his years (being that I conceive upwards of fifty) and was the next day to ride post 40 or 50 miles.” Hobson’s wife, therefore, appears to have performed the first percutaneous nephrolithotomy!

The first to insert a needle into the kidney was probably Thomas Hillier, a London pediatrician, who in 1864 removed more than 3 liters of urine from the hydronephrotic kidney of a four-year-old boy. Hillier repeated the procedure on numerous occasions during the youngster’s short life. By the
close of the nineteenth century Sir Henry Morris was able to document the performance of percutaneous renal aspiration on eighteen patients, some of whom even had iodine or other sclerosing agents instilled into their hydronephrotic sacs. Serious complications, especially peritonitis, caused the procedure to be undertaken only under the most impelling circumstances, and it was eventually abandoned. In 1954, however, Goodwin and his colleagues at the University of California in Los Angeles resurrected percutaneous puncture of the dilated renal collecting system and supplemented it by leaving a length of polyethylene tubing for drainage. In so doing, they had, in effect, recorded the first percutaneous nephrostomy (PCN), and when they injected a contrast medium into the collecting system, may have performed the first percutaneous antegrade pyelogram as well. There is good reason to believe, however, that others, who had failed to publish their cases in the medical literature and were never credited, may have preceded the Los Angeles group in draining obstructed kidneys percutaneously. Leroy, for example, in a publication dated 1990, discusses and illustrates the case of a patient who underwent percutaneous nephrostomy at the Mayo Clinic in 1942.

Interventional uroradiology as we know it today really began in 1939 when Archie Dean 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 neoplasm. Dean claimed to have had “needled” some one hundred fifty patients with both benign and malignant renal masses. He also discovered that some renal cysts do not recur or recur extremely slowly, after complete evacuation of their contents. In 1939 Fish reviewed the results of renal cyst puncture in thirty two patients including two whose cysts were cured by the instillation of 50 percent dextrose. Seven years later 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. In this fashion, differentiation between cysts and tumors was further enhanced, and puncture of renal lesions became an established diagnostic tool until modern sonographic and CT techniques made it unnecessary for this purpose. Some American urologists thought renal mass puncture was chancy and were never more than lukewarm about it; they were concerned about missing the occasional neoplasm located in the wall of a cyst.

Kapandji further expanded the utility of the needle in the upper urinary tract when in 1949 he performed manometric studies of the renal pelvis following percutaneous puncture. Kapandji’s studies served as the springboard for the later work of Robert Whitaker of Cambridge, England, who perfected the technique of pyeloureteral infusion with pressure-flow monitoring which bears his name. They also presaged the development of percutaneous antegrade pyelography which was described almost simultaneously in 1954 by Weens and Florence in the United States and by Wickbom in Sweden.

Although Goodwin and his co-workers had performed percutaneous nephrostomy in 1954, their approach was essentially blind, the markedly dilated renal collecting system allowing them to insert a large trocar with relative impunity. It remained for Bartley and his associates in Göteborg to adapt Seldinger’s method of vascular catheterization to the performance of PCN. They described their new technique wherein they employed fluoroscopic localization, guide wires, and angiographic catheters in 1965, thereby giving rise to the procedure of PCN essentially as it is still performed today.

For reasons which are not well understood, PCN was very slow to catch on and even slower to make its way into medical literature. Perhaps urologists were reluctant to accept the notion that a procedure which heretofore had...
required the skills of a surgeon (as well as a good-sized incision) could now be performed by radiologists, using local anesthesia and a needle puncture. Whatever the causes, PCN was all but ignored for ten years. To be sure, Bartley's paper in 1965 stimulated interest in PCN among a few European radiologists, but in America interest lagged behind and essentially no progress was made until the early 1970s. 446 At this time groups at both Stanford University and the University of Colorado began to experiment with Seldinger-type PCN, and in 1975 they independently and almost simultaneously reported the first American results with this technique. 447, 448 It is interesting to read Fowler's reference to the unsung pioneers of PCN's early days:

Roy A. Peterson in San Jose, California, should be credited with the development of the percutaneous nephrostomy. Indeed in the early 1970s he designed a pre-packaged percutaneous nephrostomy kit that was marketed by Perry Products of Minneapolis, Minnesota. To my knowledge, however, most of the kits were purchased by urologists in northern California. 449 Fowler spread the credit around a bit; he also acknowledged that radiologists streamlined PCN by bringing the angiographer's armamentarium to bear upon it.

These first enthusiastic reports by Fowler and his group and by Stables and his colleagues were soon followed by a flurry of laudatory reports on PCN by other Americans, among whom Barbaric, Pfister, Harris and Talner, and Burnett and Bush appear to have been the earliest to record their experiences. 450 As each new report confirmed the glowing results of the early investigators, PCN embedded itself more firmly into the fabric of uroradiology. The technology moved ahead rapidly. Nephrostomy catheters improved and contained better self-retaining mechanisms, and soon specialized guide wires and sheaths, more effective and larger dilators, and pre-packaged kits arrived on the scene making the procedure easier, more convenient, and accessible to more physicians and patients. 451 Pederson's paper showing that PCN could be performed under ultrasound guidance and, later, Haaga's demonstration that it, as well as antegrade pyelography, could be guided by CT, stimulated additional radiologists to become involved, while the shift in puncture site from the dorsal location espoused by the early American interventionists to the lateral location favored by the Europeans made the procedure safer and much more utilitarian. 452 Now it became possible to access not only the kidney percutaneously, but also the ureter, and soon techniques for stenting, dilating, and extracting objects from the ureter became routine. 453 PCN was fast becoming an icon of radiological ingenuity as it gained unprecedented popularity.

At first PCN was used solely to drain obstructed kidneys or to provide access to the ureter and, as such, was performed either by a radiologist-urologist team or, as was more likely, by radiologists alone, especially after training in the procedure became a routine part of the radiology residency. 454 The seeds of change were not long in being sown, however. In 1976 radiologist Ingmar Fernstrom and urologist Bengt Johannsson published their benchmark work on removal of kidney and ureteral stones through a percutaneous approach and thus dramatically changed the practice of urology. 455 Urologists worldwide were quick to take notice. Technical innovations were numerous and came rapidly, and soon stones both large and small, solitary and multiple, were under attack. A few authorities, especially those in whose hands traditional methods of open surgery had been quite successful, viewed percutaneous nephrolithotomy (PCNL) with caution. William Boyce, a urologist renowned for his expertise in removing kidney stones, was very concerned about leaving a nephrostomy tube in a stone-bearing kidney (which he viewed as a possible "disaster") and concerned, too, lest the management of patients with urolithiasis fall to physicians better skilled in the use of needles than in urology. 456
Despite these forebodings, PCNL grew rapidly in popularity, and by 1984 Gillenwater, a coeditor of the *Year Book of Urology*, was able to state that “percutaneous nephrolithotomy is here to stay. Patients will always choose non-surgical extraction or pulverization of stones over a surgical procedure.”

The conjoint team from the departments of radiology and urology at the University of Minnesota, consisting of Wilfredo Castañeda-Zúñiga, Kurt Amplatz, Arthur Smith (the originator of the term endourology), Ralph Clayman, and Robert Miller deserve special mention for their many valuable contributions during this period. Their contribution was formally recognized when the five collectively received the 1990 Ferdinand C. Valentine Award of the New York Academy of Medicine. At the Mayo Clinic Joseph Segura, a urologist, and radiologist Andrew Leroy were also responsible for advancing the state of the art in giant strides as they accumulated an enormous clinical experience with PCNL. The situation was not as ecumenical everywhere, however, as some urologists, playing up the inconvenience of working with radiologists, advocated going it alone.

The demonstration by the European urologist Karl Kurth and his associates in 1977 that ultrasonic energy could disintegrate stones on contact and the description of the first clinical results with this technology by Alken and his colleagues in Mainz gave any urologists who might previously have distanced themselves from PCN reason to rethink their positions. With the entire field of urolithiasis—a significant piece of the practice of urology—now up for grabs, urologists, jolted by reports that radiologists were removing small kidney stones in conjunction with PCN, were determined to reclaim the percutaneous route to the kidney and with it control not only over stones, but also of the vast panorama of uropathology which lay within easy reach of a new generation of equipment. Spurred on by these developments and the emergence of the new one-stage PCNL, many urologists now undertook to learn PCN in an attempt to uncouple themselves from radiologists and become sole purveyors of the total urolithiasis package. The ultimate expression of this desire for autonomy was the development in 1983 by Hawkins and Hunter in Gainesville and Lawson in Milwaukee of retrograde (or “inside-out”) percutaneous nephrostomy, which urologists could initiate through the cystoscope. Urologists practicing primarily in larger hospitals and teaching centers, where joint undertakings were the rule, continued their fruitful collaborations with radiologists. Barloon estimated that in the major medical centers radiologists performed approximately 96 percent of percutaneous renal procedures, while Morriseau put the figure at only 50 percent nationwide.

The invention of extracorporeal shock wave lithotripsy (ESWL) by Christian Chaussy and his associates in Munich was a tremendous accomplishment and revolutionized the management of patients with urolithiasis. From the outset, however, ESWL was destined to be almost totally within the purview of urologists with the result that, with PCNL now shoved into the background, radiologists became even further isolated from the mainstream of stone management.

With the waning of PCNL came the end of an extraordinary era—an era marked by an unparalleled degree of interdependence and side-by-side collaboration between urologists and radiologists. Radiologists, fresh from their interventional successes with establishing pathways to the kidney via needle, wire, and catheter, had been thrown together by expediency with urologists possessing clinical knowledge and an arsenal of exotic new tools but no avenue by which to utilize them. It was an ideal, if painfully short, marriage. While it lasted, it gave rise to a myriad of new creations and widened the horizons of both urology and radiology to an unprecedented level. Such symbiosis between the specialties had never happened before; the fear is that it may never happen again.

Interventional uroradiology was by

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no means limited to probing the renal pelvis and ureter. Eventually, the management of abscesses in and around the kidney also fell to the urologist and his tools. Ng in 1966 and Voegele in 1970 diagnosed a renal abscess by aspirating pus from it, while Stables and Jackson in 1974 were the first to drain a renal abscess (infected renal cyst) by percutaneously inserting a catheter into it.  

The efficacy of percutaneous drainage of abdominal abscesses was convincingly demonstrated by Gerzof in Boston and Haaga and his group in Cleveland, each of whom reported a large series of patients treated this way. Among the many patients treated by these pioneers in the field, whose work began in 1975, were a number with renal and/or perinephric abscesses. The crucial role played by cross-sectional imaging, without which the new field of percutaneous abscess drainage could never have developed to its present level, cannot be overstated.

Needle aspiration of solid renal masses (in addition to cysts) was first advocated by Dean of New York in 1939 and then by Lindem of Sweden in 1946, but the technique was never widely adopted in the United States, in spite of the high accuracy and exceedingly low morbidity rates reported by investigators such as von Shreeb. Rowley and Cooperberg feel this delay in the acceptance of aspiration biopsy in North America was due, in part, to the dearth of skilled cytologists as well as longstanding bias by surgeons in favor of larger tissue samples and an unfounded fear of complications. Biopsy of kidneys with suspected medical disease was first done by Ball in 1934 but thereafter was almost totally neglected until reintroduced seventeen years later by Iverson and Brun. While at first renal biopsies were done "blindly," Lusted and his associates introduced biopsy under fluoroscopic control in 1956. Subsequently almost every imaging modality came to be utilized in localizing the kidney for biopsy. 

Sonographic localization, first suggested by Berlyne in 1961, appears to be the most popular current method, owing in great measure to the availability of simple and effective needle guides. Prostatic biopsy was first carried out by the transrectal route by Astraldi in 1925. In 1930 Ferguson described a transperineal technique for aspirating prostatic tissue for cytological examination. The currently popular transrectal route for aspiration cytology was first employed by Franzen in 1960. Harada and his co-workers were the first to use real-time sonography for localizing the prostate for biopsy while Ragde, Aldape, and Blasko made a major contribution to diagnostic accuracy and patient comfort by adapting an automatic spring-loaded biopsy device (Biopsy) for use in the prostate gland. An interventional tour de force was accomplished by Harrison and his colleagues at UCSF, when in 1982 they successfully carried out the first interventional procedure on the fetal urinary tract in utero. Under sonographic guidance the UCSF team was able to perform, percutaneously, a vesicoamniotic shunt, decompressing the upper urinary tract of a male fetus with severe hydronephrosis secondary to posterior urethral valves. The major developments in interventional uroradiology have been nicely summarized by Fernstrom, and the highlights are outlined in Table 9.1.3.

ORGANIZING URORADIOLOGY

Looking back, it is clear that uroradiology, after a prolonged gestation, has emerged to unequivocally take its rightful place among its sister specialties. Its growth is attributable to many factors, but, undoubtedly, the glue that held them together was the excretory program—raised to a new level of excellence by the diligent efforts of physiologically oriented practitioners and investigators. Often overlooked as a factor in the rise of uroradiology, but extremely important nonetheless, was the appearance of the automatic film processor. This made it possible—indeed mandatory—to monitor programs in progress and provided an opportunity for individuals with a
strong interest in urography to take a more dynamic role in the conduct of the examinations. Since such customizing or “tailoring” required more than a passing knowledge of clinical urology, would-be uroradiologists found themselves continuously expanding their base of knowledge in this field. 495

Linked by the commonality of their dedication to urinary tract radiology, a small group of radiologists banded together in 1966 to form a uroradiological affinity group, the Uroradiology Club (“Wee Wee Club”). Numbering only fifteen at first, the group expanded progressively until by 1974, the year of its incorporation as the Society of Uroradiology (SUR), its membership had reached fifty. The SUR now numbers one hundred seventy members from sixteen countries and actively supports and promotes—through annual scientific meetings, postgraduate courses and grants-in-aid—research and dissemination of uroradiological knowledge in the United States and abroad. The SUR has been, in great measure, responsible for raising the standards of clinical and academic uroradiology and for gaining for it, in the eyes of the radiological community, equality of status with the other specialties. In 1990 the European Society of Uroradiology was established. Now, with one hundred fifteen members, it holds an important place in European radiological affairs. National radiological societies also exist in Denmark (1987), France (1990), and Sweden (1992). The French group, the Société d’Imagerie Génito-Urinaire (SIGU) was an outgrowth of the smaller Club du Rien, founded in 1965 by Michel and which may well have been the earliest organization of uroradiologists.

Equally important to the growth of uroradiology has been the acceptance of this specialty by urologists. Indeed, many urologists, as well as nephrologists, have come to view uroradiologists as invaluable clinical consultants upon whom they depend for help in solving perplexing diagnostic problems as well as in carrying out interventional procedures. It is not by accident that uroradiology got its start as a recognized specialty at institutions with strong departments of urology. The appearance in 1979 of Urologic Radiology, a peer-reviewed journal dedicated to uroradiology, enhanced the specialty’s prestige still further. Urologic Radiology was published from 1979 to 1992, when it was absorbed into the jour-

Beginning in 1908 with the appearance of Fenwick’s The Value of Radiography in the Diagnosis and Treatment of Urinary Stones, the first textbook devoted to uroradiology, the specialty has been favored with a progression of scholarly tomes dedicated to the field. Table 9.IV lists, in order of their publication, those which exerted the most influence on urological imaging between the years 1908 and 1962. A number of comprehensive multivolume treatises on uroradiology have appeared subsequently. These works (Table 9.V) attest to uroradiology’s scope and importance, have defined the specialty, and have helped to garner new respect for it.

Table 9.IV

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<tr>
<th>YEAR</th>
<th>TITLE</th>
<th>INVESTIGATOR</th>
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<td>1908</td>
<td>The Value of Radiography in the Diagnosis and Treatment of Urinary Stone</td>
<td>Fenwick</td>
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<td>1915</td>
<td>Pyelography</td>
<td>Braasch</td>
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<td>1925</td>
<td>The Radiological Examination of the Male Urethra</td>
<td>Kohnstam and Cave</td>
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<td>1927</td>
<td>Pyelography, Its History, Technique, Uses and Dangers</td>
<td>Roche</td>
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<td>1928</td>
<td>Urological Roentgenology</td>
<td>Young and Waters</td>
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<td>1931</td>
<td>Urographic Urology</td>
<td>Woodruff</td>
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<td>1933</td>
<td>Roentgenographic Studies of the Urinary System</td>
<td>Lower and Nichols</td>
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<td>1936</td>
<td>Urologic Roentgenology</td>
<td>Wesson</td>
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<td>1944</td>
<td>The Urinary Tract: A Handbook of Roentgen Diagnosis</td>
<td>Kerr and Gillies</td>
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<td>1951</td>
<td>Renal Pevis and Ureter</td>
<td>Narath</td>
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<td>1951</td>
<td>Clinical Urography</td>
<td>Braasch and Emmett</td>
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<td>1952</td>
<td>Radiologic Diagnosis of the Lower Urinary Tract</td>
<td>Beard, Goodyear, Weens</td>
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<td>1957</td>
<td>The Lower Urinary Tract in Childhood</td>
<td>Kjellberg, Ericsson,</td>
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THE FUTURE OF Uroradiology

With such exciting possibilities as physiological imaging, computerized radiology, and super-fast MR imaging, to mention only a few, inherent in tomorrow’s radiological technology, the future of uroradiology appears bright from the scientific standpoint. Organizationally, however, the picture is less clear. Ironically, with the increasing realization that CT and ultrasound were becoming indispensable to patient care, uroradiology, while propelled to new heights of diagnostic precision by these technologies, found itself beset with problems more threatening than any it had previously faced. The decline of the intravenous urogram (from a high of

Table 9.V

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<tr>
<th>YEAR</th>
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<tr>
<td>1964</td>
<td>Emmett’s Clinical Urography (1964; 1971; 1977)</td>
<td>Witten, Myers, and Utz</td>
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<td>1971</td>
<td>Atlas of Tumor Radiology: The Kidney</td>
<td>Evans</td>
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<td>1980</td>
<td>Radiology of the Urinary Tract</td>
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<td>1983</td>
<td>Uroradiology: An Integrated Approach</td>
<td>Friedland et al.</td>
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<td>1990</td>
<td>Clinical Urography</td>
<td>Pollack</td>
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</table>
ten million in 1975 to fewer than six-hundred thousand in 1994), long the sceptre of uroradiology and unambiguously under the purview of uroradiologists, was a significant loss, since it was replaced for all practical purposes by two procedures, CT and ultrasound, neither of which was destined to be under the sole control of genitourinary tract specialists. This presented a dilemma for organ-based specialists, who now had to deal with colleagues primarily concerned with advancing a technology which cut across many specialties rather than advancing imaging of a single organ system. Under the best of circumstances this loss of control of the total package of urological imaging was inconvenient for uroradiologists, but in other settings, wide geographical dispersal of equipment, scheduling problems, and divergent personalities made the unified practice of uroradiology almost impossible. The issue of whether radiological subspecialization along organ system-based or technique-based lines is best for patient care, and the future of radiological practice has been a controversial subject among radiologists. The topic was well addressed by Hartman and his colleagues in a position paper entitled "Academic Uroradiology: The Future," in which they concluded, as have many others, that organ system-oriented radiology is more likely to further the status of academic radiology over the long term.507,508

Uroradiology also finds itself under assault from other directions. The old turf problems with urologists over sonography and interventional procedures are still unresolved; fellowship training positions in uroradiology have declined, both in the number of positions offered and the number filled; and yet a new threat to the viability of not only uroradiology but many other radiological subspecialties has appeared: the certificate of added qualification (CAQ). If, as is feared, CAQs are awarded to enough subspecialties which overlap uroradiology—but not to uroradiology itself—then third-party and managed care payers may reimburse only CAQ holders, leaving uroradiology disarticulated and redistributed over a range of specialties. There is a suspicion that such a development, were radiology to let it happen, would be greeted with considerable disfavor by urologists and nephrologists who have become accustomed to working hand-in-glove with uroradiologists and are dependent upon them. These physicians and their patients would be poorly served by such a turn of events, and there are those who feel that this development would be met by an extraordinary realignment of services, perhaps even by the recruitment of uroradiologists to full-time positions in departments of urology. The suggestion that uroradiology and gastrointestinal radiology be merged into a larger category, abdominal imaging, may offer one solution to this dilemma, but this proposal has not yet found widespread support, especially in larger medical centers. Perhaps the continued fiscal pressures on radiology may force such a merger.

CONCLUSION

Thus, as we enter the second century of radiology, we leave uroradiology a far cry from that condition in which Macintyre found it in 1896. Now, its nascent potential having been exquisitely realized by the amalgamation of people and their dreams, the trick is to keep it strong, vibrant, and full of promise in the face of new challenges. But it has been accomplished before, and the thought is that it will be achieved yet again. Be it as an independent subspecialty or one merged into the larger category of abdominal imaging, regardless of whether it remains the sole purveyor of urological imaging or is forced to share procedures with urologists and/or other specialists, the subspecialty of uroradiology is well positioned to continue its enviable record of scientific and clinical accomplishment into the twenty-first century.
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