Chapter 12
The History and Development of Percutaneous Nephrolithotomy

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The standard treatment for patients with renal calculi prior to the mid 1950s was open stone surgery. The existence of a relatively avascular plane 5 mm posterior to the midline of the kidney was establish through the work of Joseph Hyrtl in 1882 and Max Brödel in 1902 [1, 2]. However, Howard Kelly, found that the landmarks were reliable in only two thirds of kidneys and thus advocated for pyelotomy as he described it as a safer operation [2]. It was not until 1941, that Rupel and Brown would perform the first nephroscopy by placing a rigid cystoscope through a nephrostomy tract so that stones could be removed during open surgery [3]. The early instruments used to explore the renal pelvis during open surgery had hard right angles so that they could reach the calyces. This was much different from the offset nephroscopes with a straight working channel that would be developed in the future for percutaneous nephrolithotomy [4].

Percutaneous Nephrostomy

Thomas Hillier, a pediatric urologist from Great Ormond Street Hospital for Sick Children described a case report in 1865 entitled "Hydronephrosis in a boy 4 years old repeatedly tapped; recovery" where he repeatedly percutaneously drained a hydronephrotic kidney in a child eventually found to have a ureteropelvic junction obstruction [5]. Willard Goodwin, the first Chair of the Department of Urology at UCLA, was the first to place a percutaneous nephrostomy tube. In 1955, while trying to perform a renal arteriogram, Dr. Goodwin placed a needle into the collecting system of a hydronephrotic kidney. He injected radiopaque contrast, thus

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S.R. Patel et al. (eds.), *The History of Technologic Advancements in Urology*,
DOI 10.1007/978-3-319-61691-9_12

performing the first antegrade nephrostogram. He then left a tube to drain the kidney, thereby placing the first modern day nephrostomy tube. In his paper he illustrates the optimal site of puncture as “five fingerbreadths lateral to the midline and at a level where a 13th rib would be if it were to exist” [6, 7]. Dr. Goodwin’s percutaneous approach would lead to the realization that a percutaneous tract could be used to access the kidney.

By 1976, Fernström and Johansson were the first to describe a technique for extracting renal calculi through a percutaneous nephrostomy under radiological control [8]. In a later paper they would illustrate the use of polythene dilators for tract dilation [9]. Instruments used to extract renal calculi under radiologic control included the Dormia basket, which was placed through a selecter device used to help aim and manipulate the basket once it was in the renal pelvis, as well as the Randall’s forceps, used under fluoroscopy for stone extraction.

Endourology and the Dissemination of PCNL

Dr. Arthur Smith, in 1978, would describe the first antegrade stent placement when he introduced a Gibbons stent through a percutaneous nephrostomy in a patient with a reimplanted ureter with a urine leak to allow the urinary leak to seal [10]. He would coin the term “endourology” to describe a closed, controlled manipulation of the genitourinary tract. Once his residents read this title, they, along with some of the radiologists, immediately changed it to the “end of urology” [11]. Dr. Smith’s early experiments would usher in the new field of endourology and forever change how we approach the treatment of renal and ureteral calculi (Fig. 12.1). One of his early papers with Drs Zuniga, Clayman and Amplatz describes a series of 63 calculi extracted from 25 patients with a high success rate [12]. The main failures occurred in stones that could not be reached due to narrow infundibula or with stones embedded in swollen mucosa. A firsthand account of the birth of endourology can be found in Chap. 7 of this text.

Dr. Smith’s collaboration with Kurt Amplatz, an interventional radiologist and medical inventor, would lead to numerous innovations which would further advance PCNL. Many wires and dilators still bear Dr. Amplatz’s name today [11] (Fig. 12.2). A number of adjunctive instruments and various stone baskets which had been developed during the era of blind-stone basketing would find immediate application in the removal of stone fragments during PCNL. In 1926, W.A. Council developed a multiple wire cage for the extraction of calculi [13]. A number of modifications to earlier extraction instruments would be made eventually leading to Dormia’s flexible extractor (1958) with a wire cage with significant tensile strength but flexible enough to cause little trauma [14].

When trying to dilate a nephrostomy tract, filiform followers on the end of angiographic catheters were originally used. Dr. Smith wrote, *“However this proved to be difficult to manipulate over a guidewire, so we designed dilators to fit over the*

Fig. 12.1 Dr. Arthur Smith, the Father of Endourology

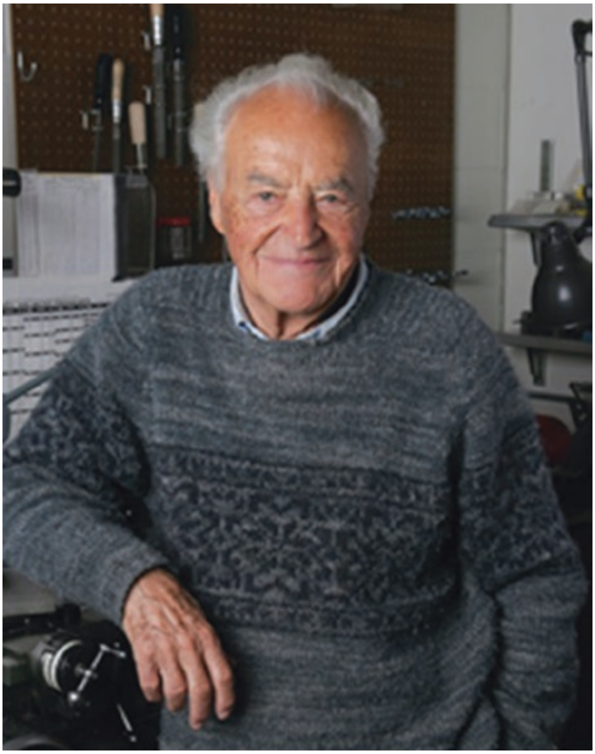

Fig. 12.2 Dr. Kurt Amplatz, radiologist and medical device inventor

angiographic catheter. We then found that we were dilating the ureteropelvic junction and causing extravasations so we placed a metal band at the tip of the dilator to differentiate the parts of the system" [11]. Much of the equipment we use today for PCNL was developed in this era. The fascial and balloon dilators that Dr. Amplatz developed are still used today and the coaxial sequential telescoping metal dilators developed by Dr. Alken were also used during this era.

Dr. Wickham describes the initial procedure as being performed over several days. After placement of a small caliber nephrostomy tube, the tract was serially dilated over several days to 22Fr to 26Fr prior to removal of the nephrostomy tube and insertion of a standard rigid 21Fr cystoscope used to access the caliceal system [12]. As the technique became more successful it was advanced to a one stage procedure.

Despite the development of PCNL, the dissemination of the technique would be largely due to the creation of the Endourological Society as well as the use of courses using the porcine model to teach the technique to practicing urologists. In 1984 at the 2nd World Congress on Percutaneous Renal Surgery in Mainz, West Germany, more than 3000 cases of PCNL were presented with a success rate exceeding 90%. It was during this time period that PCNL was deemed to be a preferable alternative to open surgery [15]. The Endourological Society was formed prior to the 3rd WCE in New York and the society and its members, under the leadership of Dr. Arthur Smith, were largely responsible for many of the innovations that would lead to the evolution of PCNL. Dr. Ralph Clayman was instrumental in helping to disseminate the technique by creating a model with the porcine kidney as a central part of teaching courses in endourology to allow the practicing urologist to adapt the procedure throughout the United States [11].

It was thus in the 1980s that PCNL underwent a rapid evolution as you saw a paradigm shift of stone treatment towards a more minimally invasive approach. The technique of PCNL gained popularity in Europe through the pioneering achievements of Alken and colleagues in Germany, Marberger in Austria and Drs Wickham and Kellet in the United Kingdom. In the United States, the technique gained acceptance following further development by Dr. Segura's group at the Mayo Clinic and with Dr. Smith and Dr. Clayman at the University of Minnesota. Initially PCNL was reserved only for patients who were poor candidates for open surgery but with rapid development in equipment and ancillary tools, PCNL would soon become the treatment of choice for large stones [4, 16].

Optics

The history of rigid optical urologic endoscopes is well documented and is covered in this text in Chap. 3 [16]. Philipp Bozzini developed his lichtleiter, or "light conductor" in 1806 for viewing orifices in the human body [17]. Antonin Desormeaux (who has been called "the father of endoscopy") would develop an open tube endoscope to examine the bladder in 1867, using his device to perform the first endoscopic surgery [16]. Maximilian Nitze and Joseph Leiter, in 1879, are credited with developing the first modern cystoscope [18]. In the late 1950s, Harold Hopkins invented the rod-lens system, which reduced the air space in between lenses with long rods of glass thereby improving the clarity and resolution of the image [19, 20]. The advances in optics led to better cystoscopes which were in turn used as the early nephroscopes. In the 1980s the rigid cystoscope would be replaced by offset nephroscopes with a large straight working channel allowing the use of numerous adjunctive instruments from triradiate graspers to electrohydraulic lithotripters [4].

Advances in illumination would play a significant role in improving the cystoscope as it evolved from indirect illumination to heated platinum wires followed by the incandescent lightbulb [16, 21]. The first fiber-optic endoscope was developed by Basil Hirschowitz in 1957 for use in gastroenterology [22]. Victor Fray Marshall would perform the first antegrade nephroscopy and ureteroscopy using a fiberscope during an open exploration to visualize the pelvis and distal ureter in 1960 [23]. Modern fiberoptics, introduced in the 1960s, coincided with the development of flexible endoscopy/nephroscopy, and aided in less invasive stone clearance. Improvements in imaging culminated with the development of the charged couple device (CCD) by George Smith and Willard Boyle in 1969 for electronic video recording [16].

Lithotripsy

Man has been breaking stone since the beginning of time. With improvements in technology, we have become increasingly efficient and safer in our ability to pulverize larger and harder stones. Thus the modern development of various lithotripsy devices and the introduction of the holmium laser have improved the efficiency of stone fragmentation and clearance [9]. In the early 1970s the ultrasonic lithotrite was developed. Karl Kurth in 1977 provided a means for removing large stones through a nephrostomy tract when he described the use of an ultrasonic lithotrite, previously developed for bladder stones, during PCNL to fragment a staghorn calculus [24]. In 1913 Reinhold Wappler would make the observation that “when a spark is brought into contact with both the hard and soft species of bladder calculi, it causes them to disintegrate” [9]. However it would not be until 1950 that LA Yutkin would obtain a patent for the application of electrohydraulic shock waves. He called his discovery the “electro-hydraulic effect,” to describe the submerged powerful high-voltage arc discharge in a liquid [25]. Pneumatic lithotripsy was introduced in the early 1990s with the development of the Swiss Lithoclast (Boston Scientific) [26]. Combined devices utilizing both ultrasonic and pneumatic lithotripsy would be developed to help facilitate stone fragmentation. The CyberWand lithotripter, a dual ultrasonic driller/corer was developed via a joint venture between Jet Propulsion Laboratories and Cybersonics, Inc. It was created in 2000 to acquire samples from planets, asteroids and comets using low power and a low axial load to drill a 0.5 in. hole in hard rocks such as basalt. It relied on a novel mechanism using piezoelectric wafers to produce high frequency vibrations which were converted to a hammering action at low frequency. The drill was used successfully to obtain core samples from locations varying from Antarctica to Mars (via the Curiosity rover). It has since been modified and revised to its current dual ultrasonic probe design to be used for PCNL [27].

Light amplification by stimulated emission of radiation (LASER) was originally described by Albert Einstein in 1917. It was not until 1954 that J.P. Gordon and C.H. Townes at Bell Laboratories generated the first stimulated emissions of microwave radiation (MASER). Medical lasers first appeared in the early 1960s [9]. The Nd:YAG, a solid state laser was developed in 1961. Mulvaney and Beck in 1968 carried out the first attempt at calculus destruction using a ruby laser [28, 29]. The introduction of the Holmium:YAG laser represented a major advance in laser lithotripsy devices as it has been shown to effectively fragment all types of urinary calculi. With the combination of flexible nephroscopy and holmium laser lithotripsy, urologists could access and fragment stones in other calyces independent of the initial renal access.

Radiology

Radiological advances would play a significant role in the development of PCNL [30]. In 2002, Dr. Segura would write:

"...it was the wide spread availablility of fluoroscopy that was the key to the popularity the percutaneous nephrostomy tube placement enjoys today. I believe that had there existed something like an "endourology table" in those days, we and not radiology, would be putting these tubes in today" [31].

In 1895 Wilhelm Röentgen observed that a high electric voltage passing through a covered vacuum tube in a dark room caused a platinocyanide covered screen to emit fluorescent light which he termed "x-rays." Röentgen's work would serve as the foundation for the field of radiology and he would be awarded the first Nobel Prize in Physics in 1902 [32]. The development of fluoroscopes, machines which consisted of a cone with an eyepiece at one end and a screen at the other end that could convert x-rays to light, in 1896, allowed one to observe an object without having to process a film or x-ray plate. The development of the image intensifier tube by J.W. Coltman from Westinghouse in the 1948, allowed an image to be intensified nearly 500 times, thus allowing the image on the screen to be visible during normal lighting [32]. Improvements in fluoroscopy would lead to the development of today's C-arms that would further aid in renal access for PCNL.

Knowledge of renal anatomy is paramount to safe access into the collecting system. In the 1990s, Francisco Sampaio's casts of the renal collecting system and vascular anatomy in human cadavers would further aid urologists by helping establish the paradigm that access to the collecting system should be obtained via direct puncture into the fornix of a calyx and not the infundibulum in order to minimizing the risk of bleeding. It would allow better characterization of the renal collecting system in comparison to the vasculature in a 3-dimensional model [33]. Besides the radiologic innovations leading to safer and more accurate renal access, the development of computed tomography by an engineer, Sir Godfrey Hounsfield (who would win the Nobel Prize in Physiology and Medicine in 1979) and a neuroradiologist, Dr. James Ambrose, would over time lead to improvements in pre-surgical planning as well as evaluation of stone free status post-operatively [34, 35].

Further Advances and Characterization of PCNL

A number of advances in technique and technology would continue to challenge how to better treat renal calculi. Dr. John Wickham reported the first tubeless PCNL in 1984 but it didn't gain acceptance until 1987 and the studies by Bellman [36, 37]. A percutaneous renal access robot (PAKY) was developed by Dr. Louis Kavoussi at Johns Hopkins for robotic needle puncture into the collecting system [38]. Supine PCNL was first described by Gabriel Valdivia in 1987 [39].

The increased clinical experience and utilization of PCNL would lead to larger studies such as the Lower Pole I study, the development of AUA guidelines for Staghorn calculi and the large scale international research projects of CROES (Clinical Research Office of the Endourological Society) on PCNL, thus leading to the characterization of stone free rates and complications for the procedure [40–42]. The use of preoperative stone scoring systems (S.T.O.N.E., Guy's and CROES Nephrolithometry scoring systems) are being used to help predict PCNL outcomes including stone free rates, length of hospital stay and complication rates [43]. As we continue to innovate, we will continue to strive to make PCNL more minimally invasive with higher success rates and a lower risk of complications.

Conclusion

An amalgam of many different technologies contributed to the development of PCNL: from the serendipity and foresight that lead to Dr. Willard Goodwin's first nephrostomy tube, the creation of the field of endourology, the advancements in optics, the development of fluoroscopy for intraoperative navigation and computed tomography for pre-operative planning, and the improvements in devices for lithotripsy (Table 12.1). These innovations culminated in the modern day PCNL and allowed us to fulfill the Hippocratic obligation that "I will not cut for stone."

Table 12.1 Timeline of Innovations in the Development of the Modern PCNL (modified from [30])

Year	Innovation [Reference]
1941	Rupel & Brown 1st Nephroscopy [3]
1950s	Development of Modern Fluoroscopy [32]
1950	LA Yutkin patent for electrohydraulic shock wave application [28]
1955	Willard Goodwin performs 1st Percutaneous Nephrostomy Tube Placement [6]
1960	1st Antegrade Nephroscopy and Ureteroscopy by Victor Fray Marshall [23]
1961	Development of Nd:YAG solid state laser [9]
1968	Mulvaney & Beck use Ruby laser for calculus fragmentation [28]
1969	Smith & Boyle develop the Charged Couple Device (CCD) [16]
1970s	Ultrasonic lithotrite developed [9]
1971	1st Computed Tomography Machine Developed by Hounsfield and Ambrose [32]
1976	Fernstrom & Johansson perform 1st stone extraction through nephrostomy [8]
1977	Karl Kurth uses ultrasonic lithotrite for PCNL of staghorn calculus [24]
1978	Arthur Smith places 1st antegrade ureteral stent [10]
1982	Ralph Clayman creates porcine model for nephroscopy and PCNL to help disseminate the technique [11]
1982	1st World Congress of Endourology, London, England
1984	Founding of the Endourological Society
1984	1st Tubeless PCNL performed by Wickham [36]
1987	1st Supine PCNL performed by Valdivia [39]
1992	Pneumatic lithotripsy developed [26]

References

1. Schultheiss D, Engel RM, Crosby RW, et al. Max Brodel (1870-1941) and medical illustration in urology. J Urol. 2000;164:1137–42.
2. Murphy LJ. The history of urology. Springfield: Charles C Thomas Publisher; 1972. p. 226.
3. Rupel E, Brown R. Nephroscopy with removal of stone following nephrostomy for obstructive calculus anuria. J Urol. 1941;46:177–82.
4. Yuhico MP, Ko R. The current status of percutaneous nephrolithotomy in the management of kidney stones. Minerva Urol Nefrol. 2008;60:159–75.
5. Bloom DA, Morgan RJ, Scardino PL. Thomas Hillier and percutaneous nephrostomy. Urology. 1989;33:347–50.
6. Palapattu GS, Bloom DA, Smith RB, Boxer RJ, Willard E. Goodwin: educator, innovator and pioneer. J Urol. 2004;172:40–4.
7. Goodwin WE, Casey WC, Woolf W. Percutaneous trocar (needle) nephrostomy in hydronephrosis. JAMA. 1955;157:891.
8. Fernstrom I, Johannsson B. Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol. 1976;10:257–9.
9. Shah J, Whitfield HN. Urolithiasis through the ages. BJU Int. 2002;89:801–10.
10. Smith AD, Lange PH, Miller RP, Reinke DB. Introduction of the Gibbons ureteral stent facilitated by antecedent percutaneous nephrostomy. J Urol. 1978;120:543–4.
11. Smith AD. A personal perspective on the origins of endourology and the endourological society. J Endourol. 2002;16:705–8.
12. Castaneda-Zuniga WR, Clayman R, Smith A, Rusnak B, Herrera M, Amplatz K. Nephrostolithotomy: percutaneous techniques for urinary calculus removal. J Urol. 2002;167:849–53.

13. Council WA. A new ureteral stone extractor and dilator. JAMA. 1926;86:1907–8.
14. Dormia E. Due nuovi apparecchi per la rimozione dei calculi dall'uretere. Urologia. 1958;25:225–33.
15. Dasgupta P, Rose FK, Wickham JE. Percutaneous renal surgery: a pioneering perspective. J Endourol. 2006;20:167–9.
16. Moran ME. History of ureteroscopy. In: Monga M, editor. Ureteroscopy: indications & technique. New York: Springer Science &Business Media; 2013. p. 3–12.
17. Engel RM. Philipp Bozzini—the father of endoscopy. J Endourol. 2003;17:859–62.
18. Herr HW. Max Nitze, the cystoscope and urology. J Urol. 2006;176:1313–6.
19. Samplaski MK, Jones JS. Two centuries of cystoscopy: the development of imaging, instrumentation and synergistic technologies. BJU Int. 2009;103:154–8.
20. Hopkins HH, Kapany NS. A flexible fiberscope, using static scanning. Nature. 1954;173:39–41.
21. Moran ME. The light bulb, cystoscopy and Thomas Alva Edison. J Endourol. 2010;24:1395–7.
22. Hirschowitz BI. A personal history of the fiberscope. Gastroenterology. 1970;36:864–7.
23. Marshall VF. Fiber optics in urology. J Urol. 1964;91:110–4.
24. Kurth KH, Hohenfellner R, Altwein JE. Ultrasound litholopaxy of a staghorn calculus. J Urol. 1977;117:242–3.
25. Denstedt JD, Clayman RV. Electrohydraulic lithotripsy of renal and ureteral calculi. J Urol. 1990;143:13–7.
26. Denstedt JD, Eberwein PM, Singh RR. The Swiss Lithoclast: a new device for intracorporeal lithotripsy. J Urol. 1992;148:1088–90.
27. Patel R, Faiena I, Elsamra S. From moon rocks to kidney stones: a look at the evolution of the cyberwand. J Urol. 2016;195(4S, supplement):e524.
28. Gross AJ, Herrmann TR. History of lasers. World J Urol. 2007;25:217–20.
29. Mulvaney WP, Beck CW. The laser beam in urology. J Urol. 1968;99:112–5.
30. Patel SR, Nakada SY. The modern history and evolution of percutaneous nephrolithotomy. J Endourol. 2015;29:153–7.
31. Segura JW. Percutaneous trocar (needle) nephrostomy in hydronephrosis. Editorial Comment. J Urol. 2001;167:829.
32. Kotecha R, Toledo-Pereyra LH. Beyond the radiograph: radiological advances in surgery. J Invest Surg. 2011;24:195–8.
33. Sampaio FJ, Zanier JF, Aragao AH, Favorito LA. Intrarenal access: 3-dimensional anatomical study. J Urol. 1992;148:1769–73.
34. Thiruchelvan N, Mostafid H, Ubhayakar G. Planning percutaneous nephrolithotomy usirn multidetector computed tomography urography, multiplanar reconstruction and three-dimensional reformatting. BJU Int. 2005;95:1280–4.
35. Park J, Hong B, Park T, Park HK. Effectiveness of noncontrast computed tomography in evaluation of residual stones after percutaneous nephrolithotomy. J Endourol. 2007;21:684–7.
36. Wickham JE, Miller RA, Kellet MJ, et al. Percutaneous nephrolithotomy: one stage or two? Br J Urol. 1984;56:582–5.
37. Bellman GC, Davidoff R. Candela et al. Tubeless percutaneous renal surgery. J Urol. 1997;157:1578–82.
38. Caddeddu JA, Stoianovici D, Kavoussi LR. Robotic surgery in urology. Urol Clin North Am. 1998;25:75–85.
39. Valdivia-Uria JG, Lanchares E, Villarroya S, Taberner J, Abril G, Aranda JM. Nefrolitectomia percutanea: Tecnica simplificada (nota previa). [Percutaneous nephrolithotomy: simplified technique (preliminary report)]. Arch Esp Urol. 1987;40:177–80.
40. Albala DM, Assimos DG, clayman RV, Denstedt JD, Grasso M, Gutierrez-Aceves J, Kahn RI, Leveillee RJ, Lingeman JE, Macaluso JN Jr, Munch LC, Nakada SY, Newman RC, Pearle MS, Preminger GM, Teichman J, Woods JR. Lower Pole I: a prospective randomized trial of extracorporeal shock wave lithotripsy and percutaneous nephrostolithotomy for lower pole nephrolithiasis-initial results. J Urol. 2001;166:2072–80.

41. Preminger GM, Assimos DG, Lingeman JE, Nakada SY, Pearle MS, Wolf JS Jr., AUA Nephrolithiasis Guideline Panel. Chapter 1: AUA guideline on management of staghorn calculi: diagnosis and treatment recommendations. J Urol. 2005;173:1991–2000.
42. Tefeki A, van Rees Vellinga S, de la Rosetter J. The CROES percutaneous nephrolithotomy global study: final report. J Endourol. 2012;26:1536–9.
43. Labadie K, Okhunov Z, Akhavein A, Moreira DM, Moreno-Palacios J, Del Junco M, Okeke Z, Bird V, Smith AD, Landman J. Evaluation and comparison of urolithiasis scoring systems used in percutaneous kidney stone surgery. J Urol. 2015;193:154–9.