JOURNAL OF ENDOUROLOGY
Volume 29, Number 2, February 2015
© Mary Ann Liebert, Inc.
Pp. 153–157
DOI: 10.1089/end.2014.0287

The Modern History and Evolution of Percutaneous Nephrolithotomy

Sutchin R. Patel, MD, and Stephen Y. Nakada, MD

Abstract

Introduction: Serendipity, innovative physicians, evolving techniques for renal access, and improvements in equipment and radiology led to the evolution of percutaneous nephrolithotomy (PCNL).

Methods: We searched urology texts and the literature for sources pertaining to the history and development of PCNL.

Results: In 1941, Rupel and Brown performed the first nephroscopy when a rigid cystoscope was passed into the kidney following open surgery. Willard Goodwin, in 1955, while trying to perform a renal arteriogram, placed a needle into the collecting system of a hydronephrotic kidney and performed the first antegrade nephrostogram. He left a tube to drain the kidney, thereby placing the first nephrostomy tube. By 1976, Fernström and Johansson were the first to describe a technique for extracting renal calculi through a percutaneous nephrostomy under radiological control. In 1978, Arthur Smith, would describe the first antegrade stent placement when he introduced a Gibbons stent through a percutaneous nephrostomy in a patient with a reimplanted ureter. Dr. Smith would coin the term ‘‘endourology’’ to describe closed, controlled manipulation of the genitourinary tract. His collaboration with Kurt Amplatz, an interventional radiologist and medical inventor, would lead to numerous innovations that would further advance PCNL. In the 1980s the process of renal access and tract dilation was improved upon and the use of a rigid cystoscope was replaced by offset nephroscopes with a large straight working channel. Radiographic innovations, including improvements in fluoroscopy would further aid in renal access. The development of various lithotripsy devices and the introduction of the holmium laser improved the efficiency of stone fragmentation and clearance. The increased clinical experience and utilization of PCNL would lead to the characterization of stone-free rates and complications for the procedure.

Conclusion: Serendipity, innovations in renal access, optics, radiology, and improvements in lithotripsy all contributed to the modern day PCNL.

Open stone surgery was the standard treatment for patients with renal calculi prior to the mid 1950s. The work of Joseph Hyrtl in 1882 and Max Brödel in 1902 established the existence of a relatively avascular plane 5 mm posterior to the midline of the kidney.[1–3] Howard Kelly, found that the landmarks were reliable in only two-thirds of kidneys and advocated for pyelotomy as he described it as a safer operation.[2,4,5] In 1941, Rupel and Brown performed the first nephroscopy by placing a rigid cystoscope through a nephrostomy tract so that stones could be removed during open surgery.[6] 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 (PCNL).[7] We explore the contributions from a wide variety of fields, primarily in the 20th century, that have led to the development of modern day PCNL.

The First Nephrostomy Tube

Willard Goodwin, the eminent urologist and the first Chairman 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 performing the first antegrade nephrostogram. He then left a tube to drain the kidney, thereby placing the first modern day nephrostomy tube. In his article he illustrates the optimal site of puncture as

Department of Urology, University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin.

five fingerbreadths to the midline of the ''13th rib'' if it were to exist.[8,9] Dr. Goodwin's percutaneous approach would lead to the realization that a percutaneous tract could be used to access the kidney.

In 1976, Fernström and Johansson were the first to describe a technique for extracting renal calculi through a percutaneous nephrostomy under radiological control.[10] In a later article they illustrated the use of polythene dilators for tract dilation.[11] Instruments used to extract renal calculi under radiologic control included the Dormia basket that was placed through a selecter device used to help aim and manipulate the basket once it was in the renal pelvis and the Randall's forceps used under fluoroscopy for stone extraction.

The Birth of Endourology

In 1978, Arthur Smith, described 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.[12] Dr. Smith would coin the term ''endourology'' to describe closed, controlled manipulation of the genitourinary tract. Dr. Smith wrote that once his residents read this title, they—along with some of the radiologists—immediately changed it to the ''end of urology.''[13] However, as we know today, this was far from the truth. One of his early articles with Drs. Zuniga, Clayman and Amplatz describes a series of 63 calculi extracted from 25 patients with a high success rate.[14] The main failures occurred in stones that could not be reached due to narrow infundibula or with stones embedded in swollen mucosa.

His collaboration with Kurt Amplatz, an interventional radiologist and medical inventor, would lead to numerous innovations that would further advance PCNL. Many wires and dilators still bear Dr. Amplatz's name today.[13]

When trying to dilate a nephrostomy tract, filiform followers on the end of angiographic catheter 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 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.''[13] Much of the equipment we use today for PCNL was developed during 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 described 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 22F to 26F prior to removal of the nephrostomy tube and insertion of a standard rigid 21F cystoscope used to access the caliceal system.[15] As the technique became more successful it was advanced to a one stage procedure.

The Beginning of the Endourological Society

1983 was the year of the First World Congress of Percutaneous Renal Surgery, the precursor to the World Congress of Endourology today, which was organized by Dr. John Wickham in London. In 1984 at the Second World Congress on Percutaneous Renal Surgery in Mainz, West Germany, more than 3000 cases of PCNL were presented with a success rate exceeding 90%. This became one of the turning points where PCNL was deemed to be a preferable alternative to open surgery.[15] The Endourological Society was formed prior to the Third World Congress of Endourology in New York and its leadership consisted of Dr. Smith as president, Dr. Segura—vice president, Dr. Clayman—secretary and Dr. Badlani—treasurer (Fig. 1). The society and its members were largely responsible for many of the innovations that would lead to the evolution of PCNL. Dr. Clayman was instrumental in creating a model with the porcine kidney to allow the practicing urologist to get a feel for the procedure and this concept would form the basis of innumerable courses in endourology throughout the United States and internationally allowing dissemination of the procedure.[13]

It was thus in the 1980s that PCNL underwent a rapid evolution as you saw a paradigm shift of stone treatment toward 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.[7,16]

Optics

The history of rigid optical urologic endoscopes is well documented.[16] Bozzini developed his lichtleiter in 1806 for viewing orifices in the human body.[17] Desormeaux developed open tube endoscopy to examine the bladder in 1867.[16] In 1879 Nitze and Leiter pioneered the first modern cystoscope.[18] In the late 1950s, Hopkins invented the rod-lens system, which reduced the air space in between lenses with long rods of glass that improved the clarity and resolution of the image.[19,20] The advances in optics led to better cystoscopes, which were used as early nephroscopes. In the 1980s

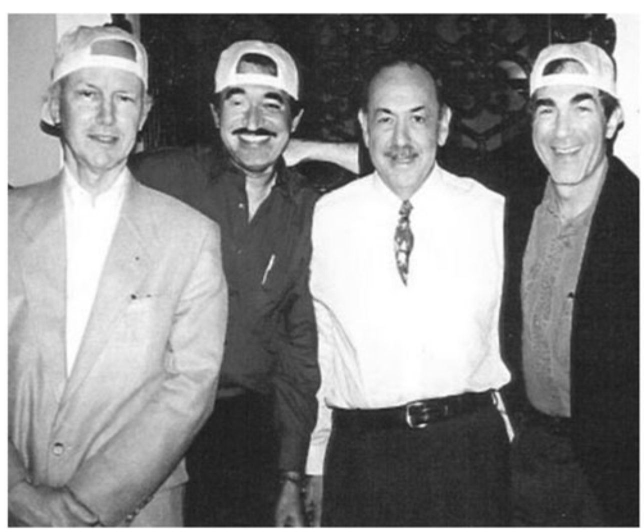

FIG. 1. Original Leadership of the Endourological Society: Drs. Segura, Badlani, Smith, and Clayman.

Table 1. Timeline of Innovations Leading to the Development and Evolution of PCNL

Year	*Access*	*Optics*	*Radiology*	*Lithotripsy*	*Innovation (Reference)*
1941					Rupel & Brown 1st Nephroscopy (6)
1950s					Modern fluoroscopy developed (30)
1950					Yutkin patent for electrohydraulic shock wave application (27)
1955					Goodwin 1st Percutaneous Nephrostomy Tube (9)
1960					1st Antegrade Nephroscopy and Ureteroscopy by Marshall (23)
1961					Development of Nd:YAG solid state laser (29)
1968					Mulvaney & Beck use Ruby laser for calculus fragmentation (29)
1969					Charged Couple Device (CCD) developed (30)
1970s					Ultrasonic lithotrite developed (16)
1971					1st Computed Tomography Machine (30)
1976					Fernstrom & Johansson 1st stone extraction through nephrostomy (10)
1977					Kurth uses ultrasonic lithotrite for PCNL of staghorn calculus (26)
1978					Smith places 1st antegrade ureteral stent (12)
1982					Clayman porcine model for nephroscopy and PCNL (13)
1982					1st World Congress of Endourology, London
1984					Founding of the Endourological Society
1984					1st Tubeless PCNL by Wickham (34)
1987					1st Supine PCNL by Valdivia (37)
1992					Pneumatic lithotripsy developed (28)
1992					Sampaio's Endocasts of Renal Vascular and Collecting System (31)

The gray shading corresponds to each of the column headings (Access, Optics, Radiology, and Lithotripsy). Each Innovation is associated with one or more of those fields and helps to show how contributions in these different fields led to the modern day PCNL.

CCD = charged couple device; PCNL = percutaneous nephrolithotomy.

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.[7]

Advances in illumination played 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 Hirschowitz in 1957 for use in gastroenterology.[22] Victor 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 by George Smith and Willard Boyle in 1969 for electronic video recording.[16]

Lithotripsy

The development of various lithotripsy devices and the introduction of the holmium laser improved the efficiency of stone fragmentation and clearance.[11] The history of lithotripsy began in the early 1800s when Morgiardini and Lando, in 1803, proposed that galvanic current could be used to dissolve calculi. In 1823 Prevost and Dumas were the first to successfully illustrate this concept when they placed a calculus in a canine bladder, filled the bladder with water and placed the stone between two platinum conductors to illustrate the use of galvanic current in stone fragmentation without damage to the bladder.[24] In 1835, Bonnet proved that by applying platinum electrodes to the opposite sides of a calculus in a solution of nitrate of potash led to the dissolution of calculi, specifically phosphate and uric acid calculi. These experiments were confirmed by Bence Jones in 1853, who also showed that this method could be used on oxalate stones, however, these experiments were all performed *ex vivo* and had never been attempted in the human bladder. In 1848, Melicher, of Vienna, used galvanic current via a voltaic pile to dissolve calculi in human patients.[25]

In the early 1970s the ultrasonic lithotrite was developed. Kurth and colleagues in 1977 provided means for removing large stones through a nephrostomy tract when he described the use of an ultrasonic device during PCNL to fragment a staghorn calculus.[26] In 1913, Wappler made 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.''[11] However, it would not be until 1950 when Yutkin would obtain a patent for the application of electrohydraulic shock waves.[27] Pneumatic lithotripsy was introduced in the early 1990s with the development of the SwissLithoclast (Boston Scientific).[28] Combined devices utilizing both ultrasonic and pneumatic lithotripsy would also be developed to help facilitate stone fragmentation.

Medical lasers first appeared in the early 1960s.[11] 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.[29] The introduction of the Holmium:YAG laser represented a major advancement in the armamentarium of laser lithotripsy devices as it has been shown to effectively fragment all types of urinary calculi. The combination of flexible nephroscopy and holmium laser lithotripsy allowed urologists to further access and fragment stones in other calyces independent of the initial renal access site.

Radiology

Radiology would play a significant role in the development of PCNL. Dr. Segura would write: ''it was the widespread availability of fluoroscopy that was the key to the popularity that 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.'' 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 of radiology and he would be awarded the first Nobel Prize in Physics in 1902.[30] Fluoroscopes, machines that consisted of a cone with an eyepiece at one end and a screen at the other end that could convert X-rays to light were developed in 1896. They allowed one to observe an object without having to process a film or X-ray plate. The development of 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.[30] These 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. A comprehensive history of the characterization of renal anatomy would be an article in itself. Its roots began during ancient times and included the contributions of the early anatomists, while transitioning to the era of early surgery and finally the contributions of radiology and imaging in further defining renal anatomy. Francisco Sampaio's studies of casts of the renal collecting system and vascular anatomy in human cadavers in the 1990s bears mentioning as it 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 to minimize the risk of bleeding.[31] Besides the radiologic innovations leading to safer and more accurate renal access, advancements in imaging, primarily the development of computed tomography, led to improvements in presurgical planning as well as evaluation of stone-free status postoperatively.[32,33]

Further Advances and the Literature

A number of advances in technique and technology would continue to challenge how to better treat renal calculi. Wickham reported the first tubeless PCNL in 1984 but it did not gain acceptance until 1987 with the studies by Bellman.[34,35] A percutaneous renal access robot (PAKY) was developed by Dr. Kavoussi at Johns Hopkins for robotic needle puncture into the collecting system.[36] Supine PCNL was first described by Valdivia in 1987.[37]

The increased clinical experience and utilization of PCNL would lead to larger studies such as the Lower Pole I study, the development of American Urological Association (AUA) guidelines for Staghorn calculi and the large-scale international research projects of Clinical Research Office of the Endourological Society (CROES) on PCNL, thus leading to the characterization of stone-free rates and complications for the procedure.[38–40]

In our historical article we have attempted to provide an overview of the many contributions, from multiple fields, that have led to the development of PCNL (Table 1). Each field's contribution could stand alone as an article and thus a limitation of our article is that we cannot cover many of the details from each field in depth and would thus recommend the reader to seek more authoritative texts in each field. Despite limiting much of our article to the 20th century, we cannot provide a comprehensive history on all of the innovations in the history of surgery, optics, and radiology that led to the development of the modern PCNL. However, we hope to provide the reader with an appreciation for the multiple facets of PCNL and how the procedure today is a culmination of the works of many different contributors.

Conclusion

Serendipity, innovations in renal access, optics, radiology, and improvements in lithotripsy all contributed to the modern day PCNL thus allowing us to fulfill the Hippocratic obligation that ''I will not cut for stone.''

Acknowledgments

The authors would like to thank Michele Paoli and the Endourological Society for the photograph used in this article.

Disclosure Statement

No competing financial interests exist.

References

1. Schultheiss D, Engel RM, Crosby RW, et al. Max Brodel (1870–1941) and medical illustration in urology. J Urol 2000;164:1137–1142.
2. Murphy LJ. The History of Urology. Springfield IL: Charles C Thomas Publisher, 1972, pp. 226.
3. Brödel M. The intrinsic blood vessels of the kidney and their significant in nephrotomy. Bull Johns Hopk Hosp 1901;12:10.
4. Kelly HA, Burnham CF. Diseases of the Kidneys, Ureters and Bladder. Vol. VII. New York: Appleton & Co., 1915, pp. 138–139.
5. Kelly HA. An address on methods of incising, searching and suturing the kidney: Delivered before the New York Medical Society. Br Med J 1902;1:256–261.
6. Rupel E, Brown R. Nephroscopy with removal of stone following nephrostomy for obstructive calculus anuria. J Urol 1941;46:177–182.
7. Yuhico MP, Ko R. The current status of percutaneous nephrolithotomy in the management of kidney stones. Minerva Urol Nefrol 2008;60:159–175.
8. Palapattu GS, Bloom DA, Smith RB, Boxer RJ. Willard E. Goodwin: Educator, innovator and pioneer. J Urol 2004; 172:40–44.
9. Goodwin WE, Casey WC, Woolf W. Percutaneous trocar (needle) nephrostomy in hydronephrosis. J Am Med Assoc 1955;157:891.
10. Fernström I, Johansson B. Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol 1976;10: 257–259.
11. Shah J, Whitfield HN. Urolithiasis through the ages. BJU Int 2002;89:801–810.
12. Smith AD, Lange PH, Miller RP, Reinke DB. Introduction of the Gibbons ureteral stent facilitated by antecedent percutaneous nephrostomy. J Urol 1978;120:543–544.
13. Smith AD. A personal perspective on the origins of endourology and the endourological society. J Endourol 2002; 16:705–708.
14. Castaneda-Zuniga WR, Clayman R, Smith A, Rusnak B, Herrera M, Amplatz K. Nephrostolithotomy: Percutaneous

techniques for urinary calculus removal. J Urol 2002;167: 849–853.
15. Dasgupta P, Rose FK, Wickham JE. Percutaneous renal surgery: A pioneering perspective. J Endourol 2006;20: 167–169.
16. Moran ME. History of ureteroscopy. In: Monga M, ed. Ureteroscopy: Indications & Technique. New York: Springer Science & Business Media, 2013, pp. 3–12.
17. Engel RM. Philipp Bozzini—the father of endoscopy. J Endourol 2003;17:859–862.
18. Herr HW. Max Nitze, the cystoscope and urology. J Urol 2006;176:1313–1316.
19. Samplaski MK, Jones JS. Two centuries of cystoscopy: The development of imaging, instrumentation and synergistic technologies. BJU Int 2009;103:154–158.
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;24:1395–1397.
22. Hirschowitz BI. A personal history of the fiberscope. Gastroenterology 1970;36:864–867.
23. Marshall VF. Fiber optics in urology J Urol 1964;91: 110–114.
24. Prevost, Dumas MM. On decomposing urinary calculi. Lond Med and Phys J 1824;51:40–41.
25. Althaus J. A Treatise on Medical Electricity, Theoretical and Practical. Philadelphia: Lindsay and Blakiston, 1860, pp. 339–341.
26. Kurth KH, Hohenfellner R, Altwein JE. Ultrasound litholopaxy of a staghorn calculus. J Urol 1977;117:242–243.
27. Denstedt JD, Clayman RV. Electrohydraulic lithotripsy of renal and ureteral calculi. J Urol 1990;143:13–17.
28. Denstedt JD, Eberwein PM, Singh RR. The Swiss Lithoclast: A new device for intracorporeal lithotripsy. J Urol 1992;148:1088–1090.
29. Gross AJ, Herrmann TR. History of lasers. World J Urol 2007;25:217–220.
30. Kotecha R, Toledo-Pereyra LH. Beyond the radiograph: Radiological advances in surgery. J Invest Surg 2011;24: 195–198.
31. Sampaio FJ, Zanier JF, Aragao AH, Favorito LA. Intrarenal access: 3-dimensional anatomical study. J Urol 1992;148: 1769–1773.
32. Thiruchelvan N, Mostafid H, Ubhayakar G. Planning percutaneous nephrolithotomy usirn multidetector computed tomography urography, multiplanar reconstruction and three-dimensional reformatting. BJU Int 2005;95:1280–1284.
33. Park J, Hong B, Park T, Park HK. Effectiveness of non-contrast computed tomography in evaluation of residual stones after percutaneous nephrolithotomy. J Endourol 2007;21:684–687.
34. Wickham JE, Miller RA, Kellet MJ, et al. Percutaneous nephrolithotomy: One stage or two? Br J Urol 1984;56: 582–585.
35. Bellman GC, Davidoff R, Candela J, et al. Tubeless percutaneous renal surgery. J Urol 1997;157:1578–1582.
36. Caddeddu JA, Stoianovici D, Kavoussi LR. Robotic surgery in urology. Urol Clin North Am 1998;25:75–85.
37. 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;40:177–180.
38. Albala DM, Assimos DG, Clayman RV, et al. 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: 2072–2080.
39. 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.
40. Tefeki A, van Rees Vellinga S, de la Rosetter J. The CROES percutaneous nephrolithotomy global study: Final report. J Endourol 2012;26:1536–1539.

Address correspondence to:
Sutchin R. Patel, MD
Department of Urology
University of Wisconsin School of Medicine and Public Health
750 Highland Avenue
Madison, WI 53705

E-mail: sutchin_patel@yahoo.com

Abbreviations Used

AUA = American Urological Association
CCD = charged couple device
CROES = Clinical Research Office of the Endourological Society
PAKY = percutaneous renal access robot
PCNL = percutaneous nephrolithotomy