

Review Article

Percutaneous nephrolithotomy: an overview

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ABSTRACT

The literature review explains what we know about kidney stones and percutaneous nephrolithotomy (PCNL) surgery. It also gives a good reason for studying how factors impact PCNL results in Central India. The guidelines from European urology advocate that PCNL is the primary choice for addressing kidney stones exceeding 2 cm. Over the period PCNL procedures have developed tremendously with the introduction of miniaturization of instruments to minimize tract size, puncture technique from fluoroscopy guided to ultrasound-guided, dilatation technique from multiple to single step dilatation, and development of newer lithotripsy techniques. The success of this treatment, often measured as stone-free rates (SFRs), depends on factors like the size and type of the stone, how the access puncture is made, the number of tracts (pathways created for the procedure), and dilation techniques

Keywords Renal stones, PCNL, Kidney stones, Stone characteristics, Electro-hydraulic-lithotripter, SFRs, central India

INTRODUCTION

The literature review aims to provide current knowledge about renal stones and PCNL and a clear rationale for investigating the factors affecting PCNL outcomes in Central India. As per Kakkar et al the prevalence of renal stones in India is approximately 12% but it is more common in North India, where it is 15%.^{1,2} According to United States national health and nutrition examination survey (NHANES) 2015-16, prevalence of renal stones in men is 13% and in females is 9.8%.³ Renal stones are a common disease affecting 12% of the population and has been associated with an increased risk of chronic kidney disease, end-stage renal failure, diabetes, and hypertension.⁴⁻⁷ Renal stones and their management constitute approximately 30% of the work in the urology department.⁸ PCNL is a gold standard procedure for kidney stones of size >2 cm but it is also associated with complications like bleeding, infection, residual stones, and radiation exposure. Currently, many options are available for the management of kidney stones other than PCNL like RIRS (Retrograde intrarenal surgery), ECIRS

(Endoscopic combined intrarenal surgery), and ESWL (Extracorporeal shock wave lithotripsy).

LITERATURE REVIEW

This literature review aims to extensively analyze current scientific knowledge on kidney stones and their treatment. The key objectives include demonstrating a breadth and depth of understanding, critically appraising existing literature, identifying research gaps, and justifying the significance of addressing these gaps. The review covers three main themes: Clinical anatomy of the kidney, kidney stones, history, technique, and recent advances in PCNL. Searches were conducted across multiple databases, including PubMed, web of science, Embase, Medline, and the Cochrane central register of controlled trials, covering studies published up to December 31st, 2023. A total of 160 series were identified, with 57 deemed relevant to the study's focus. Additionally, manual searches of article reference lists were performed. The search terms employed included "kidney stones," "kidney anatomy," "renal stones,"

"history of PCNL," "advances in PCNL," "technique of PCNL," "and "therapeutic advancement." Various search strategies utilizing Boolean operators (and, or, not) such as "kidney stone" technique of PCNL "history of PCNL" and "recent advances in PCNL," were employed. Medical subject headings (MeSH) terms were utilized in PubMed or other MeSH-indexed databases. The search and selection procedures complied with the recommendations outlined in the preferred reporting items for systematic review and meta-analysis (PRISMA) guidelines. Exclusions were made for irrelevant topics, studies lacking full-text availability, or those with insufficient data. Additionally, a manual review of datasets was conducted to identify duplicate entries or data points.

CLINICAL ANATOMY OF KIDNEY

The kidneys are organs shaped like beans, with one side concave and the other convex, weighing between 150 to 200 grams in males and around 120 to 135 gm in females. Typically, they measure 10 to 12 cm in length, 5 to 7 cm in width, and 3 to 5 cm in thickness. Positioned retroperitoneally between T12 and L3. The upper poles are usually slightly tilted towards the medial and posterior direction compared to the lower poles. Approximately 20% of the total cardiac output is directed to the kidneys.

These highly vascular organs receive blood through the renal arteries, originating from the aorta just below the superior mesenteric artery and entering the kidney at the L2 level. The renal arteries divide near the hilum, forming five segmental arteries. The posterior segmental artery supplies the back portion of the kidney, while the other four arteries arise from the anterior branch of the renal artery, named as the superior, anterosuperior, anteroinferior, and inferior segmental arteries, respectively. Occasionally, additional renal arteries, present in about 25% of individuals due to incomplete embryonic vessel degeneration, may come from the aorta or renal artery and typically enter the poles.⁹⁻¹¹

The renal veins follow a similar course as the renal arteries, traveling anteriorly. The left renal vein receives drainage from the left suprarenal vein and left inferior phrenic vein, with branches from the lumbar or hemiazygos vein connecting to the left renal vein in 75% of cases. The gonadal and renal veins typically drain separately into the inferior vena cava on the right side. Notably, all renal arteries are end arteries, lacking collateral circulation, emphasizing the need to protect any accessory arteries or branches to preserve kidney function.¹²⁻¹⁵

Brodel's line, an avascular boundary between the renal anterior and posterior end arteries, runs longitudinally from top to bottom, just posterior to the lateral convex border of each kidney. This line holds significance in renal access of creating a nephrostomy tract during PCNL and renal incisions to minimize blood loss.

KIDNEY STONES

The formation of kidney stones initiates with the crystallization of minerals in supersaturated urine, adhering to the urothelium and creating a nidus for further growth. The mechanisms anchoring crystals to the urothelium are not fully understood, with recent theories emphasizing the role of cell surface molecules influencing crystal adhesion. Calcium oxalate stones often develop on Randall's plaques, composed of hydroxyapatite crystals, providing a nucleus for calcium oxalate deposition.^{16,17}

Key risk factors for stone formation include low fluid intake, leading to concentrated urine and increased crystallization. Hypercalciuria, where high urine calcium is a prevalent abnormality, contributes to 80% of stones, primarily calcium oxalate or calcium phosphate.¹⁸ Genetic factors, such as deactivating vitamin D receptor variants, primary hyperparathyroidism, and fibroblast growth factor polymorphisms, play a role in hypercalciuria.^{19,20}

High salt intake raises urinary calcium output, potentially increasing the risk of stone formation.²¹ Factors contributing to high urine oxalate, common in calcium oxalate stones, include primary and enteric oxaluria, with intestinal oxalate transporter polymorphisms possibly influencing risk.²² Surprisingly, low calcium intake is associated with an increased risk of stone formation, as dietary calcium limits intestinal oxalate absorption.²³⁻²⁵

Hypocitraturia, linked to hypokalemia, chronic acidosis, and distal renal tubular acidosis, reduces crystallization by forming soluble complexes with calcium.²⁵ High animal protein intake leads to oxalate and uric acid formation, increasing the risk of stone nucleation. Enteric hyperoxaluria, observed in short bowel syndrome, results from increased colonic absorption of oxalate.^{27,28}

Primary hyperoxaluria, characterized by disturbed oxalate metabolism, has autosomal recessive subtypes.

Most kidney stones are calcium stones, typically calcium oxalate. The liver produces oxalate, and it can be absorbed from food. Foods like fruits, vegetables, nuts, and chocolate with high oxalate contribute to stone formation. Calcium phosphate stones prompt targeted investigations, especially for distal renal tubular acidosis (dRTA), with underlying causes explored.^{29,30} Alkaline urine promotes calcium phosphate stone formation. Struvite stones form in response to a urinary tract infection. These stones can grow quickly and become quite large, sometimes with few symptoms or little warning. Uric acid stones, prevalent in acidic urine and metabolic syndrome, may necessitate serum urate, glycosylated hemoglobin (HbA1c), and blood pressure assessments. Ileostomy patients face a higher risk due to bicarbonate and fluid losses.³¹ Cystine stones, unique to cystinuria, an autosomal recessive disorder, require early

detection and may lead to kidney failure in affected individuals.

Kidney stone investigations encompass a comprehensive approach to diagnosis. Gathering a patient's medical history unveils crucial risk factors. A physical examination may unveil abdominal or back tenderness, indicative of kidney stones. Blood tests evaluate kidney function, uncover underlying conditions like hyperparathyroidism, and measure substances influencing stone formation like uric acid, and serum electrolytes. Urinalysis detects crystals, blood, or other indicators of stone formation. A 24-hour urine collection gauges substances contributing to stone risk. Analyzing the biochemical composition of kidney stones is crucial for guiding further investigation and treatment. When stone composition data is lacking, radiology can offer valuable insights, as uric acid and cystine stones are radiolucent on plain X-rays. Stone density on unenhanced computed tomography (CT) aids in assessing larger stones. Metabolic analysis should be warranted to prevent further stone formation.

The guidelines from European urology advocate that PCNL is the primary choice for addressing kidney stones exceeding 2 cm. Subsequently, RIRS or extracorporeal shockwave lithotripsy (ESWL) are alternative treatments. If the stone size is 1 and 2 cm, ESWL and endourology are equally effective. If the stone is <1 cm, PCNL is recommended only if RIRS or ESWL is contraindicated.³²

HISTORY, TECHNIQUE, AND RECENT ADVANCES IN PCNL

In 1902 Max Brodel said that there was a relatively avascular plane 5 mm posterior to the midline of the

kidney.³³ In 1941 Rupal and Brown did the first nephroscopy.³⁴ In 1955 Dr. Goodwin placed the first needle in the kidney and did an antegrade nephrostogram and put the first nephrostomy tube Fernstrom and Johanson first described PCNL in 1976.^{35,36} Dr. Arther Smith did first antegrade stenting with Gibbons stent and used endourology word in 1978.³⁷ Dr. Smith in collaboration with Dr. Kurt Amplantz and Dr Anken developed serial plastic and metal dilators respectively. PCNL is one of the most popular techniques of management of stones of size >2 cm, partial, complete, and multiple staghorn, ESWL refractory stones, lower calyceal stones. It is also useful in the removal of calyceal diverticular calculi, stones in the horseshoe kidney, and ectopic kidney.³⁸ Over the period PCNL procedures have developed tremendously with the introduction of miniaturization of instruments to minimize tract size, puncture technique from fluoroscopy guided to ultrasound-guided, dilatation technique from multiple to single step dilatation, and development of newer lithotripsy techniques from EHL (Electrohydraulic lithotriptor) [Ballistic-ultrasound to lasers. Shift from older to newer imaging techniques, i. e., plain X-ray-KUB to Computerized tomography KUB scan (CT KUB) providing better diagnosis, better planning for the procedure, and better prognosis in the form of developing scoring system like S.T.O.N.E nephrolithometry score and Thomas et al came out with Guy's stone score and Smith et al developed CROES.^{39,40} Mishra et al developed Staghorn morphometry by using CT urography along with CT-based volumetric assessment software and is also used as a prognostic tool for PCNL outcomes.⁴¹ Agarwal et al said that tubeless PCNL in uncomplicated cases reduces patient morbidity.⁴²⁻⁴⁴ This newer approach called Totally Tubeless PCNL is a technique in which urologists do not place nephrostomy or ureteral catheter, especially in uncomplicated PCNL.⁴⁵⁻⁴⁷

Table 1: History of PCNL.

Year	Access	Optics	Radiology	Lithotripsy	Innovations/reference
1941					Rupel and Brown 1 st nephroscopy
1950s					Modern fluoroscopy developed
1950					Yutkin patent for electrohydraulic shock wave application
1955					Goodwin 1 st percutaneous nephrostomy tube
1960					1 st antegrade nephroscopy and ureteroscopy by Marshall
1961					Development of Nd: YAG solid-state laser
1968					Mulvaney and Beck use Ruby laser for calculus fragmentation
1969					Charged couple device (CCD) developed
1970s					Ultrasonic lithotrite developed
1971					1 st CT machine
1976					Fernstrom and Johansson 1 st stone extraction through nephrostomy
1977					Kurth uses ultrasonic lithotrite for PCNL of staghorn calculus
1978					Smith places 1st antegrade ureteral stent
1982					Clayman porcine model for nephroscopy and PCNL
1982					1 st world congress of endourology, London
1984					Founding of the endourological society
1984					1 st tubeless PCNL by Wickham

Continued.

Year	Access	Optics	Radiology	Lithotripsy	Innovations/reference
1987					1 st supine PCNL by Valdivia
1992					Pneumatic lithotripsy developed
1992					Sampaio's endocasts of renal vascular and collecting system

The yellow shading corresponds to each of the column headings (Access, optics, radiology, and lithotripsy). Every innovation is connected to specific fields, and by looking at these fields, we can see how advancements in each one played a role in shaping the modern PCNL. CCD=changed couple device, PCNL=percutaneous nephrolithotomy.

Technique

The patient was put in general anesthesia. Six Fr ureteric catheter was placed into the kidney using a cystoscope and guided by fluoroscopy. The patient was then positioned prone, and retrograde pyelography (RGP) was done to outline the kidney's structure and renal access. The target calyx was punctured using an 18-gauge needle, guided by fluoroscopy using either the Bull's eye or triangulation technique.

Once the puncture was confirmed, a guide wire was passed through the needle and directed into the ureter. If multiple paths were needed, multiple punctures were made, and wires were passed through them. The puncture site was gradually widened first with 10 Fr dilators and then with telescopic dilators over a central guide rod up to 24 or 30 Fr, guided by fluoroscopy. An appropriately sized Amplatz sheath was inserted, and a rigid nephroscope was used to visualize and break down stones with pneumatic lithotripsy (EMS).

Stone fragments were then retrieved and a double “jj” stent was placed. In some cases, a nephrostomy tube was put for 24-48 hours. On the first post-op day, check ultrasound, X-ray, and hemoglobin levels were performed. The nephrostomy tube was removed after 24 hrs, regardless of whether all stones were completely removed, as we don't typically perform a second-look procedure. The success of the procedure was determined by finding no visible stones on ultrasound or X-ray, or if any remaining fragments were less than 5 mm. Patients with remaining stones were scheduled for a different treatment (ESWL) at a later time. Complications were assessed and categorized based on a standardized Clavien classification system. Revolutions in PCNL techniques were done from time to time like Standard PCNL with sheath size 24-30 F and 18 Fr scope in 1980, Mini PCNL with sheath size 14-20 F in 1998 and 12 Fr scope, Micro-perc with sheath size 4.85 in 2011, and Mini-micro PCNL. Ultra-mini (UMP) PCNL with sheath size 11-13 F and 3Fr scope in 2013.⁴⁸⁻⁵⁰

Recent advances in PCNL

Recently by using a nephrometry score, one can predict the number of tracts and number of stages of PCNL. According to Proietti et al supine PCNL is gaining popularity in the Galdakao-modified Valdivia position with several potential advantages.⁵¹ Jones et al indicate that, in the evolution of PCNL, the thulium fiber laser plays a crucial advantage over the classic HO: YAG laser

in terms of smaller fiber diameter, less retropulsion, higher frequency, and less lithotripsy time.⁵² According to Leila Moftakhar et al elderly patients of age 50-60 years have a higher chance of kidney stones than 40-50 years and are associated with a higher rate of complications and hospital stay.⁵³ Jiao et al showed in their study that Single-tract PCNL is safe and effective with less blood transfusion and fewer complications than multitrack PCNL.⁵⁴ Zhang stated that one-shot dilation is safe and effective and reduces access time, fluoroscopy time, and less decrease in hemoglobin than serial dilation.⁵⁵ Anastasiadis et al revealed that 1250 HU stones have a better stone-free rate than very low and very density calculus.⁵⁶ As per Ganpule et al the large lower calyceal stones have low SFRs and high retreatment rates.⁵⁷

CONCLUSION

PCNL, is the usual method for treating large kidney stones bigger than 2 cm. The success of this treatment, often measured as SFRs, depends on factors like the size and type of the stone, how the access puncture is made, the number of tracts (pathways created for the procedure), and dilation techniques. Thanks to advancements like smaller instruments and newer lithotripsy techniques to break up the stones, PCNL continues to be a reliable choice with reasonable rates of complications.

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