# Minimally Invasive Stone Surgery: Percutaneous, Ureteroscopic and Extracorporeal Approaches To Renal and Ureteral Calculi

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**The goal of treating renal and ureteral** calculi is to achieve complete stone clearance with minimal morbidity. The treatment depends on various factors, including stone size, composition and location, clinical "patient factors", availability of the equipment and the surgeon's capability. Recent prospective trials suggest that ureteroscopy provides certain advantages over **shock wave therapy** (SWL) for the management of distal ureteral calculi.[1] Nevertheless, several surgical options are available for the treatment of proximal ureteral calculi and renal calculi. Recent advances in both technology and physiologic understanding have led to improvements in the management of urinary stone disease and allow for a variety of surgical options with decreased patient morbidity.

Calculus disease that requires surgical intervention is typically managed by three different modalities and is dependent on the factors stated above. Generally, ureteral calculi are managed either by SWL or **ureteroscopy with lithotripsy** (URS). Renal stones are typically managed by the above two modalities as well as **percutaneous nephrosolithotomy** (PNL).

**Medical expulsive therapy** (MET) is defined as the use of pharmacologic means to facilitate passage of ureteral stones. These medications are typically alpha blockers with or without the addition of a steroid. This is an acceptable first line option for ureteral stones that are < 1 cm in size. This should be under close urologic supervision as rigorous imaging and evaluation of renal function are necessary to ensure that these patients do not develop renal insufficiency, obstruction, sepsis, or poorly controlled pain which would warrant urgent intervention.

## Surgical Treatment Options

### SWL

Shock wave lithotripsy was first introduced in the 1980s. The mechanism of stone fragmentation is focusing high intensity acoustic pulses generated extracorporally on the target stone. The stone is targeted by fluoroscopy or ultrasound. The first shock wave lithotripter (Dornier HM3) required patients to be submerged in a water bath under general anesthesia and it achieved excellent results. This device was difficult to use, costly and required significant resources to run. As a result it is no longer in use. Newer machines have eliminated the need for the water bath, no longer require general anesthesia and cost less. Again, stones are localized by fluoroscopic and/or ultrasound guidance. The patient's flank is positioned over a coupling device and acoustic shock waves are generated to lead to fragmentation of the targeted stone.

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New concepts in SWL have improved the compressive component of the shockwave by altering timing and pattern of the acoustic shockwaves. Additionally manipulation of the total energy delivered to the stone has been shown to enhance stone fragmentation while decreasing peripheral tissue damage. Efficacy of SWL can be predicted to a limited degree based on patient body habitus, skin-to-stone distance, the houndsfield unit measurement of the stone on CT scan, or stone composition (if known prior). Complications of SWL include steinstrasse, infection, renal hematoma and ureteral injury, all of which occur less than 5% of times.

### Ureteroscopy with Lithotripsy

Over the past 15 years, as ureterorenoscopes have become smaller with improved optics, the efficacy of the retrograde ureteroscopy for renal and ureteral calculi has improved. Rigid ureterorenoscopes typically range from 6-12 F and flexible scopes are range between 6 –9 F. Ureteroscopy is performed with the patient under anesthesia in the lithotomy position. Use of fluoroscopy is necessary for retrograde evaluation of the ureter and renal pelvis as well as to ensure proper positioning of safety wires and endoscopes. The ureteroscopes are advanced up the ureter in the retrograde fashion and lithotripsy is performed with a holmium/Yag laser. Overall perforation rates of less than 2 % have been described when using predominantly small-caliber ureteroscopes.[2] In a recent series of 1,000 ureteroscopic procedures no ureteral perforations occurred.[3]

When considering late postoperative complications, ureteral stricture is one of the most concerning. It may be a consequence of ureteral trauma from instrumentation or from calculus impaction. The rate of stricture formation has notably decreased with a decrease in size of the ureteroscope and improvements in ureteroscopic technique. Stricture rates of less than 1% using small-caliber semi rigid and flexible ureteroscopes have been reported whereas early reports using 9.5F to 12.5F ureteroscopes cited stricture rates of up to 4 %[2].

### PNL

Fernstrom and Johansen in 1976 first described the technique of removing a kidney stone percutaneously.[23] Since then advances in technology, technical skill, and understanding of physiological principles have allowed percutaneous stone retrieval with increasing efficiency. Traditionally PNL is reserved for large renal calculi and specific instances for treatment of complex impacted large proximal ureteral calculi. Increasing evidence, however, suggests that the indications for PNL may be broadened to include treatment of smaller stones because of PNL's high stone-free rates with minimal complications.

Percutaneous access is gained with the patient in the prone position. The collecting system is typically opacified via a retrograde catheter with an occlusion balloon. With fluoroscopic or ultrasound image guidance placement of a needle percutaneously from the flank through renal parenchyma and into the collecting system is then performed. The percutaneous tract is then dilated to allow access into the kidney for stone removal. Tra-

**Table 1. Comparing clinical results of holmium laser ureteroscopy and SWL in the management of proximal ureteral stones**

| | References | | |
|---|---|---|---|
| | 16 ; Lam et al. | 15; Parker et al. | 14; Wu et al |
| **Years of study** | 1997-2001 | 1997-2001 | 2002-2003 |
| **Number of procedures** | 81 | 220 | 80 |
| **Methods** | Retrospective | Retrospective | Prospective |
| **No. in SWL** | 50 | 111 | 41 |
| **No. in URS** | 31 | 109 | 39 |
| **Machine** | Dornier Doli 50 | Dornier HM4 or Donier Doli-S | Medispec |
| **Stone < 10 mm** | | | |
| **Successful SWL;** | 80% | 60% | All stone larger than 10 mm; mean stone size SWL = 12.8 mm, URS 15.1 mm |
| **Successful URS;** | 100% | 90% | |
| **P value** | - | <0.0001 | |
| **Stone ≥ 10 mm** | | | |
| **Successful SWL;** | 50% | 45% | |
| **Successful URS;** | 93% | 93% | |
| **P value** | - | <0.0001 | |
| **Overall stone free rate** | | | |
| **SWL** | | 55% | 61 |
| **URS** | - | 91% | 92 |
| **P value** | | <0.001 | 0.003 |
| **Complications SWL(n) Major/Minor** | **Minor**; Renal colic, none required hospital admission | **Overall**; 33.3%, **Major**;1.8% (1 urosepsis, 1 pyelonephritis | Flank soreness (more common in SWL group) and gross hematuria; none required admission |
| **Complications URS(n) Major/Minor** | None | **Overall**: 28.4%. **Major**: 6.4%(1 perforation. 1 urosepsis. 1 pyelonephritis, 2 cardiac complications. 2 ureteral stricture) | |

ditionally, postoperatively patients are left with a temporary nephrostomy tube which aids in drainage of the renal unit and also allows for tamponade of the renal parenchyma. Nephrostomy tubes are generally removed before patients are discharged from the hospital. Absolute contraindications to PNL include bleeding diathesis and acute infection. Complications include bleeding injury to adjacent organs including lung, colon, spleen and liver.

Stone-free rates for PNL depend on preoperative stone burden and imaging modality to determine efficacy. In recent studies stone-free rates for all renal calculi averaged 87% - 100%. [4, 5]

Advances in PNL include both "tubeless" PNL, "tubeless, stentless PNL, and bilateral synchronous PNL. With increasing efficacy of PNL new attempts at decreasing patient morbidity and discomfort have led surgeons to perform PNL without nephrostomy tubes. During these cases an internal antegrade double J stent is placed and the patients are left without nephrostomy tubes. Recent PNL studies comparing tubeless PNL to traditional PNL with nephrostomy tube have shown a significant decrease in post operative analgesic requirements, hospital stay, and operative time with equivalent stone free rates for those patients undergoing tubeless PNL. [6-8] In addition, in specific situations with uncomplicated stones, patients are left without both a nephrostomy tube and an internal stent, thereby obviating a secondary procedure to remove the stent. Preliminary outcomes from this procedure are encouraging.[9, 10]

Patients with large bilateral stone burdens have traditionally been treated with staged procedures, addressing each renal unit at different anesthetic. Recent studies have shown not only the safety but the efficacy of performing bilateral synchronous PNL, decreasing overall cost and patient anesthesia requirements. [11]

## Specific Considerations

### Staghorn Calculi

Staghorn calculi are branched stones, commonly composed of magnesium ammonium phosphate (struvite), that occupy a large portion of the collecting system. These stones are frequently denoted "infection" stones because of their association with urease-producing bacteria which cause urinary tract infections.

In 2005 the **American Urological Association (AUA)** developed guidelines for the treatment of staghorn calculi. Left untreated, staghorn calculi pose significant risk for kidney loss, sepsis and death. As a result with few exceptions, all staghorn calculi should be treated.[12] PNL is the preferred method of treatment of staghorn calculi, which has shown to have stone free rates up to 3 times higher compared to those of SWL monotherapy with the mean number of procedures to become stone free as 1.9 for PNL compared to 3.6 for SWL. In addition, open surgery should not be used for the majority of patients.

### Lower Pole Stones

Two randomized trials evaluated the efficacy of SWL, ureteroscopy, and PNL for lower pole stones based upon stone size. [13, 14] For lower pole stones < 1.0 cm in size patients were randomized to SWL and URS, patients were followed post operatively with CT scans. Surprisingly the authors found an overall stone free rate was 50% or less for either treatment modality. In addition there was no statistically significant difference in stone free rates between SWL and URS (35% compared to 50%). Therefore SWL and URS are both viable treatment modalities for lower pole stones < 1.0 cm. More recently data presented by Patel et. al. demonstrate that for lower pole stones less than <15 mm treated by tubeless PNL stone free rates were 100% compared to a similar cohort treated by URS (80%) and SWL (30%).[22]

For stones > 1.0 cm PNL achieved stone free rates 95% while SWL achieved stone-free rates of only 37%. Hospital stays were on average 2 days longer 2.66 to 0.55 for PNL compared to SWL, and complication rates were not significantly different between the two groups. Therefore it appears for stones > 10 mm PNL would be the modality of choice to achieve the best stone-free rates.

### Ureteral Calculi

In 2007 the AUA published a meta-analysis and guidelines for the management of ureteral calculi.[15] For stones within the ureter managed by SWL stone free rates depend on locations. Stone free rates are as high as are 82%, 73%, and 74% for the proximal, middle, and distal ureter respectively. Advances in optics and laser technology over the past ten years have improved efficacy of ureteroscopy. Currently ureteroscopic stone-free rates are 87%, 86%, and 96% for proximal, middle and distal ureter respectively. Based on the above data the analysis revealed that overall stone free rates for calculi in the proximal ureter were roughly equivalent for SWL and URS. However on subgroup analysis SWL had superior stone free rates for proximal ureteral calculi <10 mm. In contrast, stones > 10mm in the proximal ureter were better managed by URS.[16-18] (Table 1) Distal and mid ureteral calculi were best managed by URS.

### Pediatrics

For pediatric patients with ureteral stones both SWL and URS appear viable options. Children are able to pass stone fragments after SWL more easily than adults. Ureteroscopy can be used as a primary or secondary treatment modality followed by SWL but is often limited to the size of ureteroscope and the diameter of the patients ureter. For pediatric patients with larger staghorn calculi, SWL appears to be more effective than in adults and stone free rates can reach up to 80%.[19] Additionally PNL appears to be an efficacious treatment for staghorn calculi in children as well.

### Pregnancy

Calculus disease in the pregnant population can pose a risk to the fetus for both diagnosis and treatment. For a pregnant patient with stones in whom conservative management fails, traditional treatment with either PCN or ureteral stenting is suggested, with definitive treatment deferred until the postpartum period. However, placement of either a stent or PCN tube is not without morbidity. While pregnancy is a contraindication for SWL, recent studies have revealed the safety and efficacy of uretersoscopy for the pregnant patient. [20, 21]

Watterson and colleagues[15] reported a series of ureteroscopy with lithotripsy in pregnancy. They used the ureteroscopic laser treatment in 8 patients with 10 symptomatic ureteral stones in whom conservative treatment failed. There were 3 cases with stones in the upper ureter; one of them had an encrusted stent. The overall stone-free rate in this series was 89%. Two of the proximal ureteral stones were treated successfully. In one patient who presented an encrusted stent at 35 weeks of gestation, the stent was removed successfully and definitive stone treatment was deferred until the postpartum period. There were no obstetric or urologic complications.

## Conclusions

We have presented clinical data, including technical considerations and complications, for PNL, URS and SWL treatment modalities. The AUA has set guidelines for treatment of urinary calculi. In many situations, however, there are multiple treatment options. ALL of these options are standard of care in Rhode Island. According to the 2007 AUA Ureteral Stone Clinical Guidelines, SWL or URS are recommended first line treatment options for ureteral stones. SWL has been less successful in treatment of larger calculi and often requires multiple treatments. With the development of small flexible ureteroscopes and holmium laser technology, treatment of larger and more complicated ureteral and renal stones can be effectively and safely performed ureteroscopically, even in high risk patients, in a single setting and should be considered the treatment of choice for these situations. Guidelines for treatment of renal stones are less clear because AUA guidelines have been developed for staghorn renal calculi only. For small renal stones < 2cm, SWL and URS are acceptable first line therapies; however, consideration of stone location and renal anatomy may impact the choice of therapy with increasing evidence suggesting that PNL may be acceptable for treatment of smaller lower pole renal stones with minimal patient morbidity and excellent stone free rates. PNL should be considered the first line therapy for patients with large renal calculi or staghorn renal calculi. With surgeons experienced in these techniques, patient morbidity and complication rates are low while outcomes are excellent.

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### Disclosure of Financial Interests

The authors have no financial interests to disclose.


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