Surgical Treatment: Urolithiasis

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1. Introduction

The prevalence in stone disease has doubled over the last 30 years, with a reported prevalence of 11% of the U.S. population in 2022, up from 9% in 2012 and 5.2% in 1994.[1-2] While prevention is the cornerstone of patient management, when patients do present with symptomatic urolithiasis they require appropriate surgical management. Constant improvement in endoscopic technology has led to a change in the recommended management for stone disease. Therefore, this Core Curriculum will discuss the surgical management of urolithiasis, from the initial diagnosis of an acute stone event to surgic management in the patient requiring intervention.

1.1 Key words

Shock wave lithotripsy, Ureteroscopy, Percutaneous Nephrolithotomy

2. Radiographic Evaluation

Historically, **plain abdominal radiography** and **intravenous pyelography (IVP)** comprised the standard imaging studies that guided surgical planning. However, plain radiography is unable to visualize radiolucent stones, is poorly sensitive for stones overlying the bony pelvis, limited in obese patients and provides no information on collecting system anatomy. IVP overcomes some of the disadvantages c plain radiography, because stones may be visualized as filling defects within the renal collecting system. Employing tomographic techniques as an adjunct to pyelography can prevent the overlying bowel contents from obscuring stones and may provide more detailed images. Administration of intravenous contrast also provides functional data on collecting system dynamics in addition to anatomic delineatic However, exposure to contrast is associated with risk of allergic reaction or renal toxicity. Furthermore, few institutions offer IVP imaging since computed tomography (CT) urographic imaging has become widely available.

Although less commonly used for surgical planning, **renal ultrasonography** nonetheless provides information on kidney stone burden and collecting system anatomy and has the additional benefit of being inexpensive with no ionizing radiation exposure. However, renal ultrasound poorly visualizes stones located in the ureter and has **limited sensitivity for stones less than 2-3 mm in size**. Visualization of ureteral jets within the bladder can be used as an adjunct to evaluate for ureteral obstruction. Despite its limitations, ultrasound remains the initial imaging study of choice for pregnant patients with renal co Additionally, sonography may be the preferred method of follow up imaging for chronic stone formers to assess for recurrence.

Radionuclide studies are uncommonly used for the planning of stone treatment. Their primary utility lies in the functional information they provide, particularly with regard to quantifying degree of obstructior and defining the distribution of global renal function.

Unenhanced helical CT scanning has emerged as the standard imaging modality for patients requiring surgical stone treatment.[4] CT rapidly acquires images and provides information on **stone burd location, collecting system anatomy, relational anatomy of the kidney** and **ureter** and **perinephric findings** such as urinary extravasation, stranding or inflammation. CT imaging also provides inform that can influence surgical treatment planning, such as **Hounsfield unit (HU) density** of the stone and **skin-to-stone distance (SSD),** both of which have been reported to correlate with SWL outcomes.[5] **Stones with a HU less than 900-1000 HU and SSD <9-10 cm are associated with significantly better treatment outcomes than stones with HU >1000 or SSD >10 cm**. CT imaging (dual-energy) sh promise in predicting stone composition.[6] However, overlap of HUs among stones of different composition and the fact that many stones are mixed composition currently limits the usefulness of CT in predicting stone composition. The primary drawback of CT imaging is the associated **radiation exposure**. However, with current "low dose" CT protocols, radiation exposure can be minimized.

Although the long-term effects of repeated CT exposure have not been well characterized, there is concern regarding the deleterious effects of ionizing radiation in patients undergoing repeated CT imaging such as recurrent stone formers.[7] **Low-dose and even ultra-low-dose imaging protocols** have emerged as a means to lower the exposure to ionizing radiation without significantly compromising on sensitivity. Compared to a standard-dose CT of 5-7 mSv of radiation exposure, low-dose CT averages less than 3.5 mSv, and ultra-low-dose can achieve less than 1.9mSV of exposure. When limiting ultra-low-dose CT to just the kidneys (as might be done for surveillance imaging) radiation exposure averages only 0.57 mSv which is within range of the 0.5-0.7 mSv experienced from a single KUB X-Ray

Low-dose CT techniques should be utilized in pediatric patients with suspect ureterolithiasis in whom renal ultrasound is non-diagnostic. Likewise, pregnant patients with a suspected stone in the second or trimester can undergo low-dose CT imaging if ultrasound is non-diagnostic. [11] Additionally, sonography is re-emerging as the imaging modality of choice for the follow-up of patients treated for renal and ureteral calculi because of the lack of ionizing radiation[3]

Radiation exposure is a concern to both the patient and physician, and efforts should be made to minimize exposure during image-guided surgical treatment as well as during diagnostic imaging. **The use "last image hold", pulsed and low-dose fluoroscopy protocols, and strategic shielding can help reduce radiation exposure**. Likewise, the use of leaded aprons, gloves, thyroid collars and glasses further protect the surgeon from ionizing radiation (see AUA Core Curriculum: **Radiation Safety**).[12]

3. The Acute Stone Episode: Indications for Intervention

3.1 History and Physical Examination

The evaluation of a patient with a suspected acute stone begins with a complete history and physical examination, the goal of which is to establish the diagnosis and develop a treatment plan.[13] The medica history should provide information regarding the location, onset, duration, and nature of the pain. A history of previous urinary tract surgery or reconstruction should be elicited. Physical examination should include vital signs and a careful abdominal and genitourinary examination. **Fever greater than 100° F or tachycardia and hypotension should raise suspicion of obstructive pyelonephritis** and mandates a focused investigation for this condition.

3.2 Laboratory Studies

The laboratory examination should include a complete blood count in patients who are considering surgical intervention, metabolic panel if there is a concern for decreased renal function, and a urinalysis**. I patients with clinical or laboratory signs of infection a urine culture should be obtained.**[14] **The presence of leukocytosis or pyuria should raise concern for pyelonephritis**. If a urine dipstick assessment is performed the presence of leukocyte esterase or nitrites indicate possible infection; however, a mild leukocytosis is very common likely due to inflammation without evidence of an infection. Blood urea nitrogen (BUN) and serum creatinine serve as indicators of renal function and may influence the decision regarding need for intervention.

3.3 Radiographic Evaluation

The preferred imaging modality for patients with a suspected ureteral stone is an unenhanced CT.[13-14] CT has superior diagnostic accuracy compared to intravenous urogram or renal ultrasound. Although unenhanced CT imaging does not provide functional information, it can suggest the presence of obstruction on the basis of secondary signs (**hydroureteronephrosis, urinary extravasation, perinephric** or **periureteral stranding**). If the plan is for trial of passage a plain abdominal radiograph (kidneys, ureter, bladder - KUB) should be obtained if a ureteral stone is identified on CT. If the stone visible on KUB then it can be used to follow the progress of the stone over time. If the patient has complex renal anatomy or history of GU surgery then additional intravenous contrast imaging can be bene in developing a treatment plan.

3.4 Pain Control

Once the diagnosis of a stone is made, the focus is on pain control. Non-steroidal anti-inflammatory agents (NSAIDs) and opioid analgesics are the most commonly used medications for the management c acute renal colic.[15] A meta-analysis of randomized clinical trials comparing NSAIDs with opioids for the management of acute renal colic showed that although both drugs effectively relieved pain, NSAIDs were associated with a greater reduction in pain scores than opioids[15] NSAIDs directly inhibit the synthesis of prostaglandins, thereby decreasing activation of pain receptors and reducing renal blood flow a ureteral contractions. These agents are generally well tolerated, but side-effects include gastrointestinal complaints, platelet dysfunction, and renal functional impairment. NSAIDS have the advantage over opioids of not causing respiratory depression or reduced bowel motility. The most commonly used NSAID in the setting of acute renal colic is ketorolac (15-30 mg IV). **Ketorolac is contraindicated in patients with renal failure or those with a history of gastrointestinal bleeding, hypersensitivity to aspirin or other NSAIDs, or in nursing or pregnant women.**[13] With increasing scrutiny on the utilization of opioids, the AUA has provided in an **Opioid Use Position Statement**. Patient education remains paramount for managing expectations and improving satisfaction with their post operative pair control and outcomes. The Urology Care Foundation has several patient resources including a **Pain Management Fact Sheet**. A comprehensive summary of the **Opioid Stewardship in Urology: Quality**

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Improvement Summit 2018 is also available for a multidisciplinary approach on reducing post operative pain and improving appropriateness of opioid prescriptions.

3.5 Management of Obstructive Pyelonephritis

Urgent drainage of a renal unit is indicated in the setting of obstruction and signs of infection (fever, leukocytosis, and/or hemodynamic instability).[14] Drainage may be accomplished with either nephrostomy or stent placement as both approaches have been shown to have comparable outcomes in a randomized trial.[13-16] Patients with uncontrolled pain or high grade renal obstruction may also ben from timely drainage. At present, as both percutaneous nephrostomy and ureteral stent are considered to be appropriate therapies, the decision as to which is the most appropriate for a particular scenario depend on institutional characteristics. Examples of different clinical scenarios would be as follows: is interventional radiology readily available, or is it more expeditious to proceed to the operating room for stent placement; is the patient too unstable for general anesthetic for a stent placement and would be better served with minimal sedation and percutaneous nephrostomy tube placement. Further discussio on this subject can be found on the AUA Core Curriculum **Consults & Emergencies: Upper Tract Obstruction**.

3.6 Medical Expulsive Therapy

In patients with normal renal function, no signs of infection, well-controlled pain and a reasonable likelihood of spontaneous stone passage (<10 mm in size in the distal ureter), observation w medical expulsive therapy (MET), that is the use of agents which may facilitate stone spontaneous stone passage is recommended.[14] However, it must be noted that Medical expulsive therapy (M for ureteral stones has become a controversial area due to the contradictory results of high-quality trials and meta-analyses.[17] The most commonly used medications for MET are alpha blockers (tamsulosin mg daily), which act to relax the ureter and potentially promote stone passage.[18] **Patients should be advised that prescribing these agents for MET constitutes an "off label" use of the drug**. In addi they should be aware that tamsulosin use can be associated with "intraoperative floppy iris syndrome", and the drug should be avoided if cataract surgery is contemplated and/or the patient should notify th ophthalmologist of its use. If the patient fails to pass the stone over a 4-6 week period or trial of passage requires significant narcotic support or trips to the emergency department then MET and trial of passage should be abandoned and surgical treatment of the stone instituted.

4. Shock Wave Lithotripsy

4.1 Shock Wave Physics

All shock waves have both a positive pressure component and a negative pressure component. The **positive pressure component**, also known as the **compressive phase**, can produce pressures rangi from **20-100 MPa**. The **negative pressure component** of the shock wave produces pressures of **-5 to -15 MPa**. During lithotripsy, the repetitive administration of shock waves creates small fractures in the targeted stone. Over the course of a treatment session, these small cracks grow, and eventually lead to stone fragmentation. In general, fragmentation of stones occurs as a consequence of the stresses induced by the applied shock waves. With repetitive stresses from repeated shock wave administration, these cracks grow and lead to fragmentation.[19]

4.2 Comminution Mechanisms

The fragmentation, or comminution, of stones, occurs due to several mechanisms**: shear stress, spall fracture, superfocusing, squeezing, cavitation,** and **fatigue.**

Shear stresses are generated as the shockwave passes into the stone; as the shock wave interacts with the lateral walls of the stone, shear stresses occur. Materials that consist of layers, such as kidney stones, are particularly susceptible to shear waves.

Spall fracture occurs after the shock wave enters the stone and subsequently reflects from the rear of the stone. The distal stone/urine interface reflects the shock wave back to the interior of the stone, wh results in a large tensile stress.

Superfocusing is the amplification of stresses inside the stone due to the geometry of the stone. As the shock waves reflect within the stone, regions of high stress can develop due to the internal refractio of energy.

Squeezing occurs because of the difference in sound speed between the stone and the surrounding fluid. The shock wave inside the stone propagates more rapidly than the shock wave in the fluid outside stone. This results in a circumferential stress on the stone.

Cavitation refers to small bubbles that grow in the fluid surrounding the stone in response to the large negative pressure component of the shock wave. As these bubbles collapse, a micro jet of fluid impac the stone surface.

Fatigue is the process that can occur in the stone at sites of material imperfections. These imperfections will concentrate stress, and will grow in to micro-cracks, then macro-cracks, and ultimately fragmentation will result.

4.3 Design of Lithotripters

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Table 1

Generator Type	Mechanism of Action	Advantages	Disadvantages
Electrohydraulic	Underwater spark discharge creates spherical shockwave that's focused using an ellipsoid reflector	Most effective at breaking stones	Wide pressure fluctuations from shock to shock. Short electrode life.
Electromagnetic	Produces either flat plane waves focused by an acoustic lens or cylindric waves focused by a parabolic reflector	Highly controlled shocks that are consistent. Wide area of induction into body lessens pain. Extremely durable	Small area of highly focused intrarenal energy results in increased subcapsular hematoma risk.
Piezoelectric	Planar shockwaves with directly converging shock fronts	Improved focusing accuracy Long service life Low-energy density at the skin reduces pain	Limited power delivery reduces stone breakage ability

4.3.1 Electrohydraulic Generator

In the electrohydraulic lithotripter (EHL), a spherically expanding shockwave is generated by an underwater spark discharge.[20] Specifically, high voltage is applied to two opposing electrodes positioned abo 1 mm apart, and the high-voltage spark discharge causes the explosive vaporization of water at the electrode tip. The advantage of this generator is its effectiveness in breaking kidney stones, but the disadvantages include substantial pressure fluctuations from shock to shock and a relatively short electrode life.

4.3.2 Electromagnetic Generator

Whereas the electrohydraulic lithotripter produces focused shockwaves by bouncing spherically expanding shocks off an ellipsoid reflector, the electromagnetic generators produce either plane or cylindrica shockwaves. The shock waves generated by electromagnetic generators are more controllable and reproducible than those of electrohydraulic generators. Other advantages include the introduction of ene into the patient's body over a large skin area, which may cause less pain. This generator will deliver several hundred thousand shockwaves before requiring servicing, thereby eliminating the need for frequ electrode replacement, which is required with most electrohydraulic machines. A disadvantage of this design is that the small focal region of high energy is associated with an increased rate of subcapsular hematoma formation and possibly reduced stone breakage rates.

4.3.3 Piezoelectric Generator

The piezoelectric lithotripter produces planar shockwaves with directly converging shock fronts. The advantages of this generator include improved focusing accuracy, a long service life, and the possibility an anesthetic-free treatment because of the relatively low-energy density at the skin entry point of the shockwave. A major disadvantage of this system is the limited power it delivers, which hampers its abi to effectively break renal stones. The piezoelectric energy sources produce some of the highest peak pressures of any lithotripter, but the actual energy delivered to the stone per shockwave pulse is sever orders of magnitude lower than that delivered by an electrohydraulic machine.

4.4 Imaging

There are two imaging modalities that can be used for stone localization during SWL: fluoroscopy and ultrasound. The primary advantages of **fluoroscopy** include its familiarity to most urologists and the ability to visualize radiopaque calculi throughout the urinary tract, to use iodinated contrast agents to aid in stone localization, and to display anatomic detail. The disadvantages include exposure of the sta and patient to ionizing radiation, high maintenance demands of the equipment, and inability to visualize radiolucent calculi without the use of radiographic contrast agents. A significant advantage of **ultrasonography** is the lack of ionizing radiation. In addition, ultrasonography can localize poorly opaque or non-opaque calculi. However, sonographic localization of a kidney stone requires a highly traine operator and it is difficult to target stones in the middle third of the ureter or in the presence of an indwelling ureteral catheter.

4.5 Indications and Contraindications

The **location of the stone in the kidney** has been shown to influence the success rate of SWL. **Lower calyceal stones have lower success rates** than stones located elsewhere in the kidney, likely rela to the gravity-dependent location of the lower pole that may hinder clearance of fragments.[21-22] Anatomic features may also influence fragment clearance. An **acute infundibulopelvic angle, narrow or lo infundibula and multiple infundibula are all thought to be unfavorable factors** for stone fragment passage.[23]

Location in the ureter also affects stone free rates. After an extensive meta-analysis the AUA surgical treatment of stone disease guidelines found that although SWL had the lowest complication rate (difference noted only with ureteral perforation 3.2% URS and 0% SWL) the stone free rates were lower when ureteral stone were treated with SWL vs. ureteroscopy (72% vs. 90%).[14] Furthermore, URS wa more likely than SWL to successfully treat a ureteral stone with one surgical procedure. For distal ureteral stones, SWL was not recommended over ureteroscopy due to significantly lower stone free results Patients should be counselled on these differences. If after appropriate counseling a patient chooses to undergo SWL for a ureteral stone, **routine stent placement is not recommended** as it does not increase stone-free rates and increases morbidity.

Stone size is the greatest predictor of SWL success.[24] **As stone size increases, SWL success rates decline** and the need for ancillary procedures and retreatments rises. In general, **stones < 10 mm i size are well-treated with SWL** . For stones between 10-20 mm in size, additional factors such as stone composition and stone location should be taken into account; in these cases, SWL should be rese for stones with a favorable composition and in a favorable location. If stones are located in the lower pole of the kidney and are greater than 10 mm in size SWL is not recommended. [14] Stones > 20mm in have low success rates and require more treatment sessions with SWL, and alternative approaches should be considered.

The **composition** of a stone influences the ease with which it fragments with SWL.[25] **Cystine** and **brushite calculi are the most SWL-resistant, followed by calcium oxalate monohydrate, struvite, calcium oxalate dihydrate, and uric acid stones**. Of note, stones of the same composition may fragment differently due to the variations in the ultrastructure of the stones. The **AUA surgical manageme of stone disease guidelines** recommend against SWL for cystine stone disease due to overall SWL-resistance and for uric acid stone disease due to difficulties in localization.[14]

Certain **CT parameters** can be used to select patients more likely to be treated successfully with SWL.[26] Although CT-derived stone attenuation coefficient (HU) has been investigated for use in predicting stone composition; overlap of CT HUs among stones of different composition has limited its use in this regard. **However, HU density has been shown to correlate inversely with stone free rates. HU > 900-1000 are associated with poor stone free rates**. Likewise, skin-to-stone distance (SSD), the average of measurements from the skin to the stone at 0^0, 45^0 and 90^0, has been shown to correlate inversely with stone free rates. **SSD > 9-10 cm is associated with SWL failure**. Evidence of anatomic or function obstruction distal to the stone is considered a contraindication to SWL.[14]

4.6 Adjunctive Procedures

Placement of a ureteral stent in the setting of SWL is not associated with an improved stone-free outcome for most renal and ureteral calculi.[14,27,28] Only for large stone burdens (> 2 cm) has ste placement been associated with reduced adverse outcomes because of the generation of a large volume of fragments.

Based on the success of MET for the spontaneous passage of ureteral calculi, the use of pharmacologic therapy to promote fragment expulsion after SWL has been investigated.[26] **MET, using both tamsulosin and nifedipine, has been associated with improved stone-free rates compared to placebo or no treatment.**[14]

4.7 Acute Complications

4.7.1 Renal Injury

SWL induces acute injury in renal tissue (**contusion, hemorrhage**). Virtually all patients undergoing SWL for renal stones will demonstrate hematuria within several hundred shock waves. Although in mos cases this renal injury is minor and self-limited, moderate to severe renal injury can occur and will manifest as a renal hematoma. **Depending on the lithotripter used, the settings selected, and the imaging modality used for follow-up, hematoma rates can vary from 1-40%.**[29-30]

4.7.2 Steinstrasse

Steinstrasse, ("street of stones") describes the accumulation of obstructing stone fragments in the ureter following SWL. The incidence of steinstrasse correlates directly with an increasing stone burden, a can occur in up to **10% of patients undergoing SWL**. The spectrum of presentation for steinstrasse is variable, from asymptomatic to severe renal colic, infection, or renal insufficiency. **Although the placement of a ureteral stent prior to SWL can reduce the complications associated with steinstrasse, it does not reduce the occurrence**. Placement of a nephrostomy tube can relieve the obstru and allow spontaneous resolution in many cases. If intervention is required, SWL of a lead fragment, ureteroscopy or a percutaneous approach can be used.

4.7.3 Hypertension

It has been reported that a small proportion of patients undergoing SWL *may* develop **hypertension** requiring antihypertensive medication, but this has been the subject of much debate.[29,31,32] **Age has be implicated as a significant risk factor for post-SWL hypertension**, with an increase in intrarenal resistive index observed in patients ≥ 60 years of age undergoing SWL. The mechanism of hypertensior after SWL is not well elucidated. Although subcapsular hematomas can induce hypertension, such changes are generally transient.

4.7.4 Diabetes

The high acoustic pressure from a lithotripter may extend beyond this zone. One retrospective long-term follow-up study of patients who underwent SWL suggested that patients undergoing treatment for renal calculi were at increased risk for developing **diabetes mellitus** compared to a control population.[29,31] However, this finding has not been corroborated by a large population study from the same institution.[33]

4.7.5 Renal Impairment

There has long been concern about the potential of SWL to cause **long-term reduction in renal function.**[29] However, large studies with long-term follow-up have failed to confirm these reports of deterioration of renal function. The **2021 AUA Update Series Complications of SWL** dives further into the management of complications stemming from shock wave lithotripsy.

4.8 Special Considerations

4.8.1 Pediatrics

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In general **SWL of stones in children** is associated with higher stone-free rates than in adults. However, **retreatments are common, although complications are infrequent.**[34] The developing kidney m be more susceptible to the bioeffects of SWL, and therefore this intervention should be undertaken with appropriate caution in children. Despite theoretical concerns of damage to the developing kidney, th **AUA surgical management of stones guidelines** state that SWL or ureteroscopy are equivalent treatment option for ureteral stones or renal stones ≤20 mm in the pediatric patient due to high stone free rates. Furthermore, SWL can be considered for renal stones >20 mm if a ureteral stent is placed at time of treatment.[14]

4.8.2 Renal Ectopia

In **renal ectopia**, due to overlying bowel and bony structures, SWL treatment of stones in ectopic renal units can be challenging and is often associated with **lower stone free rates.**[35,36] Prone positioning o placement of a ureteral catheter to permit retrograde instillation of contrast may facilitate localization and effective treatment.

4.8.3 Fusion Abnormalities

The position of the **horseshoe kidney,** which is typically closer to the iliac crest and more anterior than the normal kidney makes SWL challenging with low overall stone free rates.[23] The medial, anterior location of stones in the mid and lower pole calyces markedly increases the shock wave path, making focusing the shock waves on the stone more difficult. Repositioning the patient prone or elevating the ipsilateral flank may facilitate stone targeting and treatment.

4.8.4 Obesity

Obesity may limit the effectiveness of SWL due to weight limitations of the lithotripter and inability to accurately image the stone.[36,37] **Increased body mass index has been reported to be a negative predictor for SWL outcome**, and a skin-to-stone distance > 10 cm has been shown to be associated with reduced stone-free rates.[26]

4.8.5 Reproductive Concerns

Despite case reports of successful SWL treatment in pregnant women, **pregnancy is considered a contraindication to SWL** because of the theoretical risk to the fetus by shock waves. Likewise, **SWL treatment of mid and distal ureteral calculi in women of child-bearing age is considered a contraindication** because of concern for injury to the ovaries, although no increased rate of infertility or miscarriage has been reported in this setting[36,38] Men treated with SWL for distal ureteral stones have been reported to have alterations in sperm parameters immediately following treatment, although thes alterations resolved at three months of follow-up.

5. Percutaneous Nephrolithotomy

5.1 Indications

PCNL is generally reserved for large (≥ 2 cm) and complex stones, staghorn calculi, lower pole renal stones > 1 cm, or stones in complex renal anatomy.[14,20] Stones of compositions that are relatively shock wave-resistant, such as cystine or brushite, or stones for which complete clearance of all fragments is necessary, such as struvite, are well treated with PCNL. Abnormal renal anatomy that precludes ureteroscopy or impairs fragment passage after SWL is also appropriate for PCNL. Due to the risk of potential complications PCNL should not be performed in the pregnant patient, or those with uncorrected coagulopathies, or untreated urinary tract infection or in those with a body habitus that precludes safe positioning and access to the kidney.

5.2 Preoperative Considerations

All patients undergoing PCNL should have a sterile urine culture or should have been appropriately treated with culture-specific antibiotics and should receive preoperative antibiotics.[14,39] W two clinical trials demonstrated a benefit of 1 week of antibiotic therapy prior to PCNL, even in the setting of a negative pre-operative urine culture a recent randomized prospective multi-institutional investigation demonstrated no difference in infectious complications in patients receiving preoperative antibiotics with a negative pre-operative urine culture.[40,41,42] **AUA Best Practice Policy recommends first or second generation cephalosporin or gentamycin and metronidazole or clindamycin within 24 hours of the procedure.**[39]

A preoperative computed tomography (CT) is recommended prior to PCNL to define the stone burden, reveal the relational anatomy of the kidney and identify any renal anomalies.[14] Contrast studies, intravenous or CT urogram, can further define intrarenal anatomy.

PCNL can be performed in the prone, supine or lateral position, or any modification of these positions.[43] The prone position has been standard for PCNL because of the increased working area on the flank and easy access to the posterior and upper pole calyces. The supine position was introduced to simplify positioning and reduce pulmonary compromise. Furthermore, supine position can simplify combined retrograde ureteroscopy at time of PCNL.

5.3 Positioning

Historically, PCNL has been performed in the prone position with variations arising in 1998 with the introduction of supine positioning.[44] Theoretical benefits of supine positioning include decreased position time, lower operating intrarenal pressure due to downward angulation of the access, reduction in complications associated with the prone positioning such as respiratory restriction, and decreased risk of colonic perforation as the bowel is not compressed laterally as it is in prone positioning.[45] Randomized trials have shown an average of 30 min reduction in OR time with supine access, similar stone free ra and fewer high grade (Clavien ≥3) complications. Limitations of supine access include increased difficulty and accessibility of upper pole access, and limited mobility of the access sheath. [46] The prone spli position has also gained traction in recent years as similar to supine positioning, it allows for combined antegrade and retrograde endoscopy, and endoscopic guided percutaneous access.[47]

5.4 Percutaneous Access

If **ultrasound**[48] or CT guidance is utilized to obtain percutaneous access, opacification of the renal collecting system is unnecessary; however, fluoroscopic guidance relies on delineation of the collecting system with contrast or air by way of a ureteral catheter or occlusion balloon. If the collecting system cannot be accessed due to obstruction or urinary diversion, the renal pelvis can be punctured directly o the needle can be directed onto the stone[49,50] Once urine is aspirated, contrast can be instilled directly to opacify the collecting system and allow selection of a more appropriate calyx. **Ultrasound guided access** offers the benefit of minimizing radiation to the surgeon and patient even when combined in a hybrid approach.

Percutaneous access to the kidney should be performed directly through a posterior calyx/papillae in an attempt to pass through the **plane of Brodel** and limit potential bleeding.[51,52] **While a recen randomized trial demonstrated that access through an infundibulum does not pose an increased risk for post-operative hemorrhage, a puncture directly into the renal pelvis risks vascular injury**[53] Stones located in anterior calyces can generally be accessed via a posterior puncture using flexible nephroscopy. The optimal site of puncture should provide access to the largest stone burden usi rigid instruments. **Upper pole access** is best suited for **complete staghorn calculi**, **complex lower pole stones, stones in horseshoe kidneys** and **large proximal ureteral calculi.** However, upper po access is associated with a higher complication rate and more postoperative pain.

Fluoroscopic guided access can be achieved through one of 2 techniques: **eye of the needle or triangulation**.[51,52] Eye of the needle is generally considered easier to perform because the C-arm is placed such a way as to position the needle like a bulls-eye on the selected calyx, and depth of puncture is gauged by angling the C-arm away from the operator. In the triangulation technique, the needle is place the direction of the selected calyx. Then the C-arm is angled cephalad and lateral to determine the medial-lateral orientation of the needle. Once that is established, the C-arm is moved medially to determi the cephalo-caudad orientation. Triangulation requires more precise needle manipulation but the kidney can be accessed from any location on the skin with limited torque force. Additionally, ureteroscopic guided fluoroscopic access has been advocated by some urologists to improve access accuracy into a specific calyx. Similarly, retrograde nephrostomy access through a flexible ureteroscope or positioned catheter allows for placement of a puncture wire through the papilla to the flank, from inside to outside, under fluoroscopic guidance. Retrograde nephrostomy techniques minimizes trauma to the kidney ar requires less radiation to perform than antegrade.[54,55]

A **21 or 18-gauge Chiba needle or an 18-gauge diamond tip needle** is used to puncture the selected calyx. Entry into the collecting system is confirmed by aspiration of urine. A soft, atraumatic guidewi such as a hydrophilic guidewire is negotiated down the ureter, if possible, then later exchanged for a stiffer working wire. A**second guidewire is placed as a safety wire**.

5.5 Access size

See Update Series (2021) **Lesson 22: Mini Percutaneous Nephrolithotomy: An Update on Technological Advances and Role in Clinical Practice**.

Dilation of the tract with either sequential fascial dilators (Amplatz dilators) or a dilating balloon allows placement of a working sheath to facilitate entry and exit of the nephroscope and to promote egress of fluid, thereby maintaining low intrarenal pressure[51,52] Most working sheaths are 24-30F with **Mini-PCNL** terminology referring to sheath sizes from 14-22F, Ultramini PCNL 11-13F and Micro-PCNL(4.85-10F

Table 2

	Standard	Mini	Ultramini	Micro
PCNL Sheath Size	24-30Fr	14-22Fr	11-13Fr	4.85-10Fr

PCNL and Mini-PCNL have demonstrated nearly equivalent stone free rates compared to Ultramini-PCNL leading to significantly higher retreatment rates with Ultramini-PCNL (12.1% compared to 6.8% wi PCNL and 4.2% with Mini-PCNL). Complication rates are similar between Mini-PCNL and Ultramini-PCNL (4.2% and 2.4%) while both were significantly lower than standard PCNL (13.6%).[57-58] High quality data on Micro-PCNL is limited but it appears to be a safe option for small and medium size stones, in the adult or pediatric population, with fewer complications and blood loss than Ultramini-PCNL with sim stone free rates.[59-60]

5.6 Stone Extraction

Stone removal is accomplished by way of rigid and/or flexible nephroscopy.[61-62] A rigid nephroscope is the most efficient instrument as it allows for use of variety of lithotripsy devices and either aspiration or retrieval of fragments. The flexible nephroscope allows access to calyces remote from the calyx of entry and should be utilized after stone removal in all cases to ensure stone clearance.[14] Lithotripsy devices used with the rigid nephroscope include ultrasonic, pneumatic, combination (duel ultrasonic and ultrasonic/pneumatic), holmium laser and thulium laser.[20-43] **Holmium laser lithotripsy is most commonly used in conjunction with the flexible nephroscope if stone fragmentation is required**.

5.7 Drainage

Although traditionally, large bore nephrostomy tubes were left in place after PCNL, there is a trend recently toward smaller or no nephrostomy tubes, with or without placement of an internal ureteral stent.[63] Criteria for “tubeless” PCNL are listed in **Table 3, but this criteria is slowly expanding to very few limitations.** In appropriately selected cases, tubeless PCNL is associated with less patient discomfort a shorter hospital length of stay. “**Totally tubeless**” **PCNL has also been shown to be safe in highly select patients**. However, if there is a suspicion of large residual fragments, leaving a nephrostomy tul allows repeat access to the collecting system for second look flexible nephroscopy/stone extraction.

Table 3: Indications for Tubeless Percutaneous Nephrolithotomy	
Tubeless	**Nephrostomy Tube**
No intraoperative hemorrhage	Intraoperative bleeding
No collecting system injury	Perforation of collecting system
Single access	Multiple or complex tracts
Normal renal function	Chronic or acute kidney disease
Normal coagulation profile	Coagulopathy/bleeding diathesis
Normal platelet count	Thrombocytopenia
High likelihood of stone free	Obvious or suspicion of large residual calculi

5.8 Postoperative Management

The length of stay after uncomplicated PCNL is generally 1-2 days. Although the **AUA Best Practice Policy on Urologic Surgery Antimicrobial Prophylaxis does not endorse the use of antibiotics beyond 24 hours in patients without prosthetic material (orthopedic or cardiac)**,[39] positive stone cultures or struvite stones reflect bacteria that were likely not adequately treated. **In these cases, a course of antibiotics postoperatively, perhaps including prolonged suppressive antibiotics in the case of infection stones, should be given**. Follow-up imaging studies (KUB and ultrasound) shou be obtained 6-8 weeks after surgery, and metabolic testing is performed when appropriate. Some advocate for immediate postoperative imaging (i.e. CT scan) while the nephrostomy tube is in place to determine stone free status before the nephrostomy tube is removed.[65]

5.9 Complications

Complication rates for PCNL vary from **4-61%** and include **septic complications, hemorrhage, injury to surrounding organs** and **collecting system injury.**

5.9.1 Urosepsis

Urosepsis is one of the most dangerous complications that can occur after PCNL and the most common cause for mortality post-PCNL. Although bacteremia has been reported to occur in up to 37% of patients and 74% of patients have postoperative fever after PCNL, overt fulminant sepsis occurs in only 0.2-1.3% of patients. To prevent infectious complications, all patients undergoing PCNL should have urine culture obtained preoperatively and **positive urine cultures should be treated with ≥ 1 week of culture-specific antibiotics before surgery.** Broad-spectrum antibiotics should be administered at time of PCNL, and maintaining low intra-renal pressure with the use of a working sheath placement is imperative. Additionally, an intraoperative stone culture should be obtained during the procedure given correlation of stone culture positivity and the likelihood of developing systemic inflammatory response syndrome (SIRS)/sepsis in the post-operative period. [66]

5.9.2 Hemorrhage

Intraoperative and postoperative hemorrhage occurs in 0.4-11% of patients undergoing PCNL.[5] Most bleeding is venous and readily controlled with placement of a nephrostomy tube and allowing clot to form within the collecting system. If bleeding persists through and/or around the nephrostomy tube, placement of a tamponade balloon catheter applies pressure along the nephrostomy track and can be us to tamponade bleeding for 48 hours. **Postoperative hemorrhage that continues more than a few days** after surgery or that recurs in a delayed setting is generally due to **pseudoaneurysm, arteriove fistula, or segmental renal artery injury**. Arteriography and **superselective embolization** should be pursued promptly.

5.9.3 Visceral Injury

Any organ that surrounds the kidney has the potential for injury at time of PCNL, the most common being pleura, liver, spleen, colon, and duodenum.[51,67,68] **Pleural transgression occurs most commonly with upper pole access and results in hydropneumothorax in 5-16% of cases involving supracostal access.** Most hydrothoraces can be recognized intraoperatively by fluoroscopic inspection of the chest and can be managed conservatively with intraoperatively placement of a small bore thoracostomy tube. Injury to the liver, spleen and gallbladder occurs rarely and is usually managed conservatively with prolonged nephrostomy tube drainage, but rarely requires open exploration. Bowel injury occurs in less than 0.5% of cases, and most commonly involves the colon. Risk factors include renal anomalie neurogenic bowel, prior small bowel surgery, or very lateral access. **In the absence of peritoneal signs, the injury can be managed by withdrawing the nephrostomy tube into the bowel lumen and placing an internal ureteral stent to separately drain the colon and kidney** If peritoneal signs are present surgical exploration is warranted.

If a significant collecting system injury occurs during the course of the procedure, the case should be ended as soon as possible and the kidney should be drained with a nephrostomy tube and/or stent unt injury heals (usually a few days). **Saline should be used exclusively as the irrigant,**[14] and consequently, hyponatremia should not be a consequence of fluid extravasation.

See further discussion on **complications of PCNL in the 2021 AUA Update Series**.

6. Semi-Rigid Ureteroscopy

6.1 Indications

Semirigid ureteroscopy is generally used to treat ureteral stones below the level of the iliac vessels. Semi-rigid ureteroscopes are fiberoptic scopes that can tolerate a small amount of flexion. The distal tip is 4.9-7.5 Fr and the shaft graduates to 8.0-9.5 Fr more proximally.[69] Digital semi-rigid ureteroscopes are also available that provide improved visualization. Compared to flexible ureteroscopes, semi-rigid ureteroscopes generally have larger irrigation channels, improved visualization and a larger field of view.

6.2 Operative Considerations

A retrograde pyelogram performed prior to ureteroscopy can assess ureteral anatomy and locate the stone.[69] **Placement of a single guidewire serves as a safety wire and is used for stent placement necessary**. Ureteroscopy is performed alongside the wire under direct endoscopic visualization. Dilation of the ureter is rarely necessary for small caliber ureteroscopes; however, if the ureteral orifice will n admit the ureteroscope or for larger caliber ureteroscopes, the intramural ureter can be gently dilated with sequential ureteral dilators or using balloon dilation. Only saline should be used as an irrigant duri ureteroscopy and the fluid can be pressurized if necessary with the use of a syringe and 3-way stopcock, a commercially available single-action syringe, or an automated device. However, a recent prospe randomized study demonstrated that water irrigation was safe for uncomplicated URS and may provide superior irrigation. [70] Pressure should be kept as low as will allow good visibility so as to prevent proximal migration of the stone. **Stones are removed intact if they are no larger than the smallest caliber of the ureter or they can be fragmented with the holmium laser or pneumatic lithotripter** Electrohydraulic lithotripsy (EHL) is not recommended for the treatment of ureteral stones due to high risk of ureteral injury.[14] Anti-retropulsion devices can be used to limit proximal stone migration. **Stent placement is optional but should be used if there is significant ureteral edema, incomplete stone fragmentation or suspicion of ureteral injury.**[14] Stent placement in the uncomplicated ureterosco has been demonstrated to have mixed outcomes due to stent related discomfort, with a recent Cochrane review finding both desirable and undesirable stent related side effects.[71]

6.3 Complications

6.3.1 Perforation

Ureteral perforation occurs in up to **4% of cases as a result of balloon dilation, forceful and misdirected manipulation of the stone**, **intracorporeal lithotripsy devices and extraction devices.**[20,72] If perforation is recognized **the procedure should be terminated and a ureteral stent placed for 2-6 weeks. If the stone becomes completely extruded through the perforation, no attempt should be made to retrieve it.** If the stone is partially extruded, an attempt should be made to remove the stone in order to prevent formation of a stone granuloma and stricture. As long as a guidewire is in place, a ureteral stent can be placed and the procedure terminated. If a stent cannot be placed then a NT should be inserted.

6.3.2 Avulsion

Ureteral avulsion occurs in **less than 1%** of cases and nearly always occurs as a consequence of overly aggressive extraction of a large stones.[20,72] Avulsion generally requires open, laparoscopic or roboti repair that is usually performed in a delayed setting after the kidney is adequately drained with a nephrostomy tube.

6.3.3 Infection/Sepsis

Sterile urine should be assured prior to ureteroscopy to prevent postoperative infectious complications.[20]

6.3.4 Stricture

Ureteral stricture occurs in **0.5-4%** of cases. Risk factors include a stone impacted for ≥ 2 months and/or ureteral injury. **Because obstruction due to stricture can occur silently, post-operative imagin with renal ultrasound (and KUB if the stone was fragmented) is recommended after any ureteroscopic procedure**.[73] **This investigation should be performed approximately four-six weeks following the procedure.**

7. Flexible Ureteroscopy

7.1 Indications

Flexible ureteroscopy is indicated for the treatment of appropriate renal calculi and all ureteral calculi **at or proximal to the iliac vessels**. Flexible ureteroscopy is a good treatment option to treat renal calc ≤ 20 mm in patients who are obese, have bleeding disorders, have stone compositions resistant to SWL, who failed SWL, or have lower pole stones ≤10 mm.[14,74] Furthermore, due to the safety of URS in patients with comorbidities it may be considered for larger renal calculi as a staged surgical procedure if PCNL is contraindicated. Flexible ureteroscopes range in size from 5.2-8.7F at the tip and gradually increase in size more proximally.[69] Most flexible ureteroscopes have active primary and active or passive secondary deflection of the tip. **The working channel is 3.6F in size and accommodates ≤ 3F instruments**. However, both irrigation fluid and working instruments pass through the single working channel, and therefore the larger the instrument used, the less the irrigant flow. Passage of working instruments decrease the flexibility of the ureteroscope and can be minimized by using smaller sized instruments.

7.2 Operative Technique

In uncomplicated stone scenarios routine stenting prior to ureteroscopy is not recommended due to added patient morbidity with minimal surgical benefit.[14] A retrograde pyelogram performed prior to ureteroscopy can assess ureteral anatomy and locate the stone.[69] Two guidewires are advanced into the collecting system, a stiff working guidewire and a safety wire since the working guidewire is remove after passage of the ureteroscope. The flexible ureteroscope can be passed directly into the kidney over the working wire under fluoroscopic guidance or it can be passed through a ureteral access sheath. **Only saline should be used as an irrigant during ureteroscopy**[14] and the fluid should be pressurized with the use of a syringe and 3-way stopcock, a commercially available single-action syringe, or an automated device. Pressure should be kept as low as will allow good visibility and to prevent proximal stone migration and reduce pyelo-veneous pressure. **Ureteral access sheaths have been shown to reduce intra-renal pressure and improve stone free rates without increasing rates of ureteral stricture formation.**[20] Stones located in the proximal ureter should usually be fragmented, unless it is cl they can be safely removed intact.[75] **A ureteral stent should be left in place if there is significant ureteral edema, suspicion of ureteral** injury, ureteral stricture, other anatomical impediments to stone fragment clearance, a solitary kidney, impaired renal function, or if a secondary URS procedure is planned. In otherwise uncomplicated cases stent placement is optional.[14] **Antegrade ureteroscopy** throug percutaneous tract may be useful in the following scenarios: **large proximal ureteral stone, ureteral and large renal stones, renal transplant ureteral stones,** or **failed retrograde access**. Antegrade passage of a ureteral access sheath is helpful in the case of a modest stone burden.

Novel techniques including robotic ureteroscopy are currently under investigation. Further information on their use can be found on the **AUA 2021 State-Of-The-Art Lecture: Robotic Ureteroscopy**.

7.3 Complications

Complications of flexible ureteroscopy are generally the same as for semirigid ureteroscopy (see ***Section 5.3***).

7.4 Single Use Scopes

Single use ureteroscopes have increased in prevalence over the last 5 years with numerous companies entering this market each year. Advantages include reliability of each device, improved sterility, and potential reduction in overall price. Studies have shown equivalent performance, irrigation flow, and stone free rates compared to standard reusable ureteroscopes.[76-77] The per case costs of reusable ureteroscope vary among institutions and depend on scope costs, repair costs, involved personnel, costs of cleaning, and breakage rates; however, overall single use scopes appear to be at least cost equivalent in many settings.[78]

8. Open/Laparoscopic/Robotic Stone Surgery

In general, most stones can be treated with the minimally invasive surgical methods previously discussed including SWL, PCNL, and URS. Open/ laparoscopic /robotic surgery should not be offered as firs therapy to most patients with stones. [14] Exceptions include rare cases of anatomic abnormalities, with large or complex stones, or those requiring concomitant reconstruction. These scenarios will be discu below.

8.1 Anatrophic Nephrolithotomy

Current AUA guidelines call for limited use of open stone surgery for the treatment of staghorn calculi as PCNL is the preferred therapy for patients with such stones.[14] However,**there are a few rare situations in which open/laparoscopic/robotic surgical intervention may be indicated, such as the presence of extensive renal deformities, like infundibular stenosis, that preclude removal of all stone material within a reasonable number of procedures**In such cases, anatrophic nephrolithotomy may be the preferred approach.[20]

8.2 Pyelolithotomy

Most stones that are easily treated with pyelolithotomy are also easily treated percutaneously. However, stones in an anomalous kidney (pelvic kidney) that cannot be safely accessed percutaneously may well served by laparoscopic/robotic pyelolithotomy. [20,79,80] Ureteropelvic junction obstruction is often associated with renal calculi. Simultaneous treatment of the stones and UPJ obstruction can be perform either by a laparoscopic/robotic or open approach. In most cases, pyelolithotomy is performed at the time of laparoscopic/robotic pyeloplasty. [14,79,81] If necessary, a flexible nephroscopy can be introduced through a port site to remove calyceal stones that are not readily accessible through the pyelotomy.

8.3 Caliceal Diverticulolithotomy

Indications for laparoscopic/robotic/open diverticulolithotomy include failed previous endoscopic treatment, inability to access the diverticulum endoscopically or percutaneously, thin parenchyma or concurr open surgical procedure. **Laparoscopic/robotic diverticulolithotomy may constitute first line treatment for patients with a large, anterior, stone-bearing diverticulum.**[79]

8.4 Ureterolithotomy

In general, ureterolithotomy is reserved for extreme situations such as very large impacted stones, multiple large ureteral stones, or when concurrent open surgery is required.[79]

8.5 Nephrectomy

Partial nephrectomy or total nephrectomy is indicated when long-term obstruction has led to partial or total parenchymal and functional loss and the involved segment or kidney is a source of ongoing pain infection.[79] A renogram to assess differential function should be performed before proceeding with partial nephrectomy or total nephrectomy. **Drainage of the obstructed segment/kidney with reassessm of renal function is indicated if there is uncertainty about the degree of functional loss**.

9. Intracorporeal Lithotripsy Devices

A variety of intracorporeal lithotripters are available that differ in their safety, efficiency and versatility.

9.1 Laser Lithotripsy Technologies

9.1.1 Holmium Laser

The Holmium:yttrium-aluminum-garnet (Ho:YAG) laser has been the gold standard for laser lithotripsy for greater than 30 years. Ho:YAG lasers can efficiently fragment stones of any composition and have been utilized in laser enucleation of the prostate and tumor ablation as well. The Ho:YAG laser is a pulsed laser that has a wavelength of 2,100 nm which is highly absorbed by water, making it ideal for sto ablation. With a depth of tissue penetration of 0.4mm it has an unmatched safety profile in the urinary system. [82]

The holmium laser transmits energy through a flexible quartz fiber than can vary in size from 150-1000 micrometers, making it ideal for flexible ureteroscopy. Holmium laser lithotripsy fragments stones by of a photothermal mechanism that requires direct contact and results in vaporization of the stone. [83-84] It is successful for stones of any composition. Older laser technology allowed for low pulse energies (to 2J) and frequencies (up to 15Hz) due to concerns for overheating and degradation of the laser. Laser power has increased significantly, 120-140W and the use of variable pulse energy, pulse rate, pulse duration and pulse morphology has allowed for greater flexibility in lithotripsy.

Lithotripsy for fragmentation with stone retrieval generally performed at settings of 0.6-1.0 J and 5-10 Hz for standard low wattage lasers. When available, a longer pulse duration can reduce retropulsion of stone, either in the ureter or kidney, which can reduce operative efficiency. Current lasers can lengthen pulse duration from 350μs to 1500μs or can utilize "Moses Technology" which delivers a short durati vapor bubble prior to a longer, higher energy pulse reducing retropulsion and improved ablation rates. This increased power allows for increased pulse rates (up to 80Hz) and the ability to "dust" stones. [85] While variable, typical dusting settings utilize a low pulse energy (0.2-0.4J) and a high pulse rate (up to 80Hz) to create a fine dust (<0.5mm) which the patient then passes. While clinical data for "Moses Technology" is limited, in a randomized trial Moses technology was associated with lower procedural and reduced fragmentation/pulverization time.[86] Both basket extraction and dusting appear to have simi complication rates but basket extraction likely has a higher stone free rates.[87]

9.1.2 Thulium Fiber Laser

While the Ho:YAG laser has been the gold standard for lithotripsy, the Thulium fiber laser (TFL) represents a new laser technology that has recent approval for use in the clinical setting. Unlike the flashlamp-pumped, solid-state Ho:YAG laser, the TFL is a diode laser with the silica laser fiber doped in thulium.[88] This allows for greater power output from a much smaller fiber core. TFL operates betwee 1,908 and 1,940 nm, which is similar to the water absorption peak of the Ho:YAG laser at 2100nm. However, energy absorption of the TFL has been found to be 4-5x greater than Ho:YAG lasers which correlates with lower pulsed energies for stone ablation in the in vitro setting.[82] Instead of mirrors focusing the light energy from the laser source limiting laser fiber diameter as in Ho:YAG, TFL achieves a hig intensity of light through the 25μm optical laser fiber core which, in theory, allows for a much smaller diameter laser fiber. It is also more plug efficient, fan cooled and operates with a standard electrical wal socket (110V). Due to these improved efficiencies less heat is generated and pulse rates can be increased up to 2000Hz with pulse durations from 0.2 up to 12ms allowing for both fragmentation and dustin settings.

Although clinical efficacy data is still lacking in the TFL arena and while in vitro studies performed demonstrating improved ablation efficiency when comparing similar laser settings with the Ho:YAG laser, t TFL does appear to have significant upside with regards to flexibility of lithotripsy settings and overall lasing efficiency.

9.2 Electrohydraulic Lithotripsy (EHL)

Electrohydraulic lithotripsy is comparable to an underwater spark plug that produces a spark which vaporizes surrounding water and creates a plasma.[20,84] As the plasma expands it creates a hydraulic sho wave, and subsequently, cavitation bubbles that fragment the stone. Flexible probes from **1.6Fr to 9.0Fr** are available, allowing the device to be used with flexible or rigid endoscopes. **EHL has the lowest margin of safety of the intracorporeal lithotripsy devices, with an 8.5-40% rate of ureteral perforation and is not recommended for ureteroscopic stone extraction.**[14] As such, this device has larg been abandoned in lieu of the holmium laser and pneumatic devices**.**

9.3 Ultrasonic Lithotripsy (UL)

Ultrasound lithotripters are comprised of a handpiece containing piezoceramic crystals and a hollow probe that is connected to suction.[84] Activation of the handpiece by an electric current via a foot pedal o handpiece excites the piezoceramic crystals and generates ultrasonic waves that are transmitted down the hollow probe causing the tip to resonate at high frequency, thereby causing stone fragmentation. requires direct contact with the stone, but will effectively fragments stones of all compositions. The probe generates heat, requiring constant irrigation to prevent injury to the urothelium. Because the probe rigid, this device is used only with rigid instruments, generally for PCNL.

9.4 Pneumatic Lithotripsy

Pneumatic lithotripsy, also known as ballistic lithotripsy, consists of a handpiece containing a metal projectile that is propelled by compressed air, creating a jack-hammer effect by way of a solid probe.[20,84] These devices have a high margin of safety because they generate no heat, but they require a straight or relatively straight working channel.

9.5 Combination Devices

Combination devices are available that combine the pneumatic and ultrasonic lithotripsy and that have dual ultrasonic lithotripsy probes.[20] These devices combine the advantages of both pneumatic and ultrasonic lithotripsy and reportedly increase the efficiency of fragmentation.

10. Selection of Therapy

10.1 Renal Calculi

10.1.1 Staghorn Calculi

The AUA Guideline on the Surgical Management of Stone Disease recommends PCNL as first-line treatment for most patients with staghorn calculi, based on high stone free rate (78%), and acceptable primary (1.3%), secondary (0.4%), and adjuvant (0.2%) procedure rates and complication rate (15%).[14] The Guideline emphasizes the use of flexible nephroscopy to enhance stone free rates w PCNL. The Panel also emphasizes that staghorn calculi should not be observed but should be surgically removed if the patient is healthy enough for intervention and there is adequate renal function.

10.1.2 Non-Staghorn, Non-Lower Pole Renal Calculi

These stones comprise the majority of renal calculi, and stones < 2 cm in size can be reasonably treated with SWL or ureteroscopy.[14] Stones > 2 cm are optimally treated with PCNL. If asymptomatic the patient and physician may choose to observe the stone with routine follow-up imaging. The recent **AUA surgical management of stone guidelines** reviewed multiple natural history studies and found tha approximately 50% of asymptomatic stones will progress, but a much smaller percentage with require surgical intervention.[14] In certain situations asymptomatic stones should be treated and not observed a these include vocational reasons such as airline pilot or military, recurrent urinary tract infections, solitary kidneys or if the patient has poor access to contemporary medical care.

10.1.3 Lower Pole Renal Calculi

The lower pole calyces are unique among renal collecting system locations because of their gravity dependent location, which results in reduced clearance of fragments after SWL and URS. A multicenter RCT compared SWL and PCNL for the treatment of isolated lower pole stones and demonstrated superior stone free rates for PCNL over SWL for all stone sizes, but found acceptable stone free rates for SWL treatment of stones < 1 cm in size.[21] A second RCT compared SWL and URS and demonstrated superior stone free rates for URS for stones < 1 cm and stones 1-2.5 cm in size, but the difference for smaller stones was not statistically significant.[22] **These studies and others suggest that lower pole stones < 1 cm in size are reasonably treated with SWL or URS, and stones > 1 cm have the higl stone free rate with PCNL**.

10.2 Ureteral Calculi

The AUA and Endourological Society Surgical Management of Stones panel recommends a trial of medical expulsive therapy in patients with ureteral calculi < 1 cm who is not infected and in whom sympt are well-controlled.[14] Periodic imaging is required to assure progression of the stone and absence of high grade obstruction.[73,14] For patients requiring treatment ureteroscopy is recommended for distal ureteral stones.[14] For mid to proximal ureteral stones the patient should be counselled that URS is the procedure with the highest stone free rate, but SWL is associated with fewer complications.[14] Furthermore, ureteroscopy generally requires fewer secondary procedures than SWL.

11. Additional Resources

11.1 AUA University Endourology Podcast

Endourology

Summer School: Controversies In Surgical Stone Management - A Case-Based Instructional Course

Summer School: Surgical & Medical Management of Stones Guidelines Update

Update Series - Dusting Vs Extraction Strategies During Ureteroscopy

AUAUniversity Podcast Series: Episode No. 169

11.2 Patient Education Material

Kidney Stones

Videos

V1722

Fluoroscopic Guided Percutaneous Access: Triangulation Technique

Mini-Percutaneous Nephrolithotomy Using Endoscopic Combined Intrarenal Surgery Technique

Mini-PCNL: Tips and Tricks to Treating Moderate to Large Sized Renal Stones

Contemporary Miniaturized Percutaneous Nephrolithotomy

Mini-PCNL

Ultrasound-guided Access for PCNL

Ultrasound-Guided Access for Percutaenous Nephrolithotomy in Supine Position

Presentations

Surgical Stone Disease Presentation 1

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