Minimally Invasive and Surgical Management of Urinary Stones

Karen Hanson

Treatment of urinary stones was once entirely surgical, but recent technological advances allow stones to be treated with less-invasive methods, including extracorporeal shock wave lithotripsy, ureteroscopic and percutaneous procedures. While many stones usually pass without intervention, approximately 10% to 20% will require intervention for removal (Tolley & Segura, 2001). Surgical management of stones becomes necessary in the setting of symptomatic calculi, urinary tract obstruction, staghorn calculi (symptomatic or asymptomatic), stones in high-risk patients for infection (for example, transplant or immunocompromised patients) (Tolley & Segura, 2001). During the past 20 years, advances in imaging modalities, and endoscopic devices and shock wave lithotripsy led to significant improvements in the management of stones. Prevention of progressive or recurrent stone formation is best managed by diet, adequate fluid intake, and in some cases, dietary supplements or medications. Comprehensive management of urinary lithiasis necessitates collaboration between the urologist, urology health care professionals, and medical colleagues that possess knowledge of medical treatment.

Etiology

Stones form in the collecting system of the kidney due to a multitude of factors. Most often an imbalance of an organic substance such as calcium, struvite, urate, or cystine due to an underlying metabolic disorder leads to matrix formation in the urine. Any obstruction to urine flow can lead to stasis of the urine and increased risk of stone formation. Reduced urine volume and dehydration may tip the balance in causing stone disease due to supersaturation of the urine. Medical conditions such as Crohn’s disease lead to increased levels of certain substances that may predispose an individual to stone formation.

Hypercalciuria. Defined as a urinary calcium excretion > 200 mg/day, it is seen most commonly with increased absorption after intestinal resections (absorptive hypercalciuria). Types I and II. It is also present in primary hyperparathyroidism or resorptive hypercalciuria (an increase in 1.25 (OH₂) vitamin D that leads to increased intestinal absorption of calcium), and renal hypercalciuria, in which the parathyroid hormone increases secondarily and results in increased 1.25 (OH₂) vitamin D production leading to increased intestinal calcium absorption. Excess vitamin D production can be seen in patients with sarcoidosis and granulomatous disorders.

Hyperoxaluria. Primary hyperoxaluria is due to an enzyme deficiency (glyoxalate carboligase). However, this is usually secondary to previous small bowel resection especially of the distal ileum, pancreatic insufficiency, and dietary calcium restriction. Diets high in oxalate can exacerbate this condition.

Hyperuricosuria. This is seen in cases of a primary defect in metabolism such as gout or with excess protein breakdown in catabolic or ketogenic states. Uric acid stones always form more often in acidic urine (pH less than 5.5), and can form in individuals with excessive purine intake. These stones are radiolucent.

Cystinuria. Cystine is a byproduct of protein metabolism. An autosomal recessive congenital defect in enzyme transport will cause impairment in renal tubular reabsorption of cystine, which is relatively insoluble.

Struvite. Considered “infec-
tious stones,” they are composed of magnesium, ammonium, phosphate, and carbonate. They occur in alkaline urine (pH > 7.2) and in the presence of ammonia. They are caused by urease-producing bacteria such as Proteus mirabilis or Ureaplasma urealyticum. Struvite stones can grow large enough to fill the collecting system and can compromise renal function.

Low levels of certain substances in the urine, such as citrate and magnesium which act to inhibit stone formation, can also lead to stone disease. A more detailed discussion of the etiology of kidney stones can be found elsewhere in this issue.

**Epidemiology**

Between 120 and 140 people per 100,000 will develop urinary stones each year (Menon & Resnick, 2002). There is a 10% risk per year of developing a first-time stone. Risk for subsequent calcium oxalate stones is 10% at 1 year, 35% at 5 years, and 50% at 10 years (Menon & Resnick, 2002). Prevalence of stone disease in the United States has risen from 3.8% between 1976 to 1980 to 5.2% between 1988 to 1994 (Stamatelou, Francis, Jones, Nyberg, & Curhan, 2003).

**Age and gender.** With the exception of struvite and cystine stones, men are more likely than women to develop stones by 3:1 (Menon & Resnick, 2002). Women more commonly form struvite stones due to their increased risk of urinary tract infections. Cystine stones occur equally in both sexes. Peak incidence of stones is from the 2nd to 4th decade of life.

**Genetic factors.** Family history predisposes individuals to stone disease. Certain inherited genetic disorders can lead to stone disease. For example, cystinuria is a hereditary disorder of the abnormal renal tubule transport that causes an increase in excreted cystine in the urine. Renal tubular acidosis is a familial disorder that causes kidney stones in most patients with this disorder. Stones are rare in Native Americans, African and American blacks, and native born Israelis (Menon & Resnick, 2002).

**Socioeconomic factors.** Affluent societies have higher rates of small upper tract stones whereas large struvite stones are more common in developing countries where malnourishment and infection are common (Hess, 2002). Bladder stones tend to be more common in underdeveloped countries, and may be related to dietary habits and malnutrition (Menon & Resnick, 2002).

**Geography.** Prevalence of stone disease is high in mountainous, desert, or tropical areas. Countries with a high incidence of stones are the United States, British Isles, Scandinavian countries, Mediterranean countries, northern India and Pakistan, northern Australia, central Europe, Malayan peninsula, and China. Reasons for geographic and climate variances are unclear (Menon & Resnick, 2002).

**Climate.** Urinary stone disease is more common in sunny warm climates, and seasonally during summer months. Dehydration and increased production of 1,25 dihydroxyvitamin D (vitamin D produced by the body) from sun exposure have been proposed as possible causes.

**Hydration.** Stone formation increases significantly when urine volume is low because of supersaturation of the urine.

**Diet.** Dietary calcium, potassium, and total fluid intake reduce the risk of kidney stones in older women and men, yet supplemental calcium, sodium, animal protein, and sucrose may increase risk. In the Nurses’ Health Study, a higher intake of dietary calcium also decreased the risk in younger women, although supplemental calcium did not increase risk as seen in older women (Curhan, 2004). Urinary stone disease has recently become more prevalent in the United States, in part due to an affluent society diet rich in refined carbohydrates, salt, and animal protein and relatively low in fruits and vegetables; low intake of citrus fruit can result in hypocitraturia. Excess intake of dietary sodium, oxalate, calcium, and purines increases risk of stone disease.

**Diagnosis**

Urinary lithiasis usually commonly presents as an acute episode of ureteral or renal colic related to an obstruction or irritation of the urinary tract. Presentation may range from no symptoms, to hematuria, to vague flank pain, to severe colicky pain that is not relieved well with pain medication. For a stone to cause significant pain it is usually obstructing urinary flow or passing through the ureter. A stone in the upper ureter can cause pain that radiates to the testicles or labia; as the stone passes to the distal ureter, the pain may continue to radiate to the testicle or labia and lead to urinary urgency, frequency, hematuria, and gastrointestinal upset.

Stones may be an incidental finding on an abdominal imaging study. Most stone disease can be easily diagnosed with spiral CT. Spiral CT can identify both radiopaque and radiolucent stones (uric acid), and assess for intraabdominal abnormalities and renal anatomy. An excretory urogram or retrograde pyelogram may be needed to further assess the collecting system, especially if minimally invasive or surgical intervention is planned. Intravenous urography can further assess the renal anatomy for abnormalities such as horseshoe kidney, duplication of the collecting system, caliectasis, and assess the renopelvic angle.

**MINIMALLY INVASIVE TREATMENT**

A stone that causes symptoms, obstruction or near obstruction, or infection must be urgently
managed either non-surgically or surgically. Large stones that cause obstruction can lead to hydrenephrosis and kidney damage as well as increased risk of infection.

**Shock Wave Lithotripsy**

Extracorporeal shock wave lithotripsy (SWL) is a minimally invasive treatment that was introduced in 1980 after years of research between Dornier, Inc. and the University of Munich. This novel technology utilizes targeted shock waves or “high-energy amplitudes of pressure generated in the air or water by an abrupt release of energy in space” (Auge & Preminger, 2002, p. 1065). Shock waves are generated outside the body by a lithotripter, and are then targeted to fragment stones within the urinary tract. The three types of shock wave generators are electrohydraulic, electromagnetic, and piezoelectric. All lithotripters have an energy source, a focusing device, a coupling mechanism, and a stone localization system using either fluoroscopy or ultrasound. Fragmentation occurs through tensile stress that removes surface material, and spalling or pulverization of the stone through the application of multiple shock waves and ultimately cavitation forces (see Figure 1).

The number of shock waves required for adequate stone fragmentation depends on the composition of the stone, the focal pressure, energy density, and fluid interface. Stones that fragment easily include calcium oxalate dihydrate, uric acid, and struvite. Stones that are difficult to fragment include calcium oxalate monohydrate, cystine, and calcium phosphate (brushtite). The use of shock wave lithotripsy is dependant on the size, position, and anatomic features of the stone; SWL is less effective with large stones and in obese patients due to difficulty in getting the stone into the focal point. Once a stone is adequately treated, the fragments can then be passed spontaneously from the urinary tract.

The first lithotripter, Dornier HM-3, used a water bath into which the patient was suspended from a ceiling-mounted gantry, and required general anesthesia because powerful shock waves produced intolerable discomfort. Newer devices use a water-filled cushion placed in contact with the patient’s body to provide a coupling mechanism, use less-intensive shock waves, and typically require only conscious sedation. These newer lithotripters are probably safer than the original devices, but are also somewhat less efficacious (Menon & Resnick, 2002). Complications include acute damage to adjacent renal tissues that can lead to hematuria, subcapsular hematoma, infection caused by bacteria liberated during SWL, or obstruction and/or colic caused by passage of stone fragments. Some renal injuries may be irreversible (Menon & Resnick, 2002). Potential long-term adverse effects include elevated systemic blood pressure, decreased renal function, and increased risk of stone recurrence (Menon & Resnick, 2002). Gastric and duodenal erosions are the most common extrarenal compli-
cation of SWL. Risk factors for injury with SWL and potential contraindications include age (both young and old), obesity, coagulation disorders, solitary kidney, thrombocytopenia, diabetes mellitus, coronary artery disease, and hypertension (Menon & Resnick, 2002). A double pigtail stent may be placed for stones larger than 6 mm to prevent obstruction. The stent is removed at a followup visit. Renal or ureteral colic is painful and can be treated with antispasmodics.

Nursing care. Shock wave lithotripsy is commonly an outpatient procedure and recovery is rapid. It is minimally invasive and can be delivered under local anesthesia or intravenous sedation; typically parenteral sedatives and narcotics such as alfentanil, midazolam, and propofol are used. Topical anesthetics such as EMLA (a mixture of lidocaine and prilocaine) can reduce anesthesia requirements; this topical agent is applied at least 45 minutes prior to SWL. The procedure lasts approximately 30 to 50 minutes. Cardiac monitoring during the procedure is required to synchronize the shock waves with the patient’s EKG rhythm to prevent cardiac arrhythmias. Patients are encouraged to ambulate and increase fluid intake to flush out stone fragments. Stone passage may continue for up to 3 months after SWL (Tolley & Segura, 2001).

Ureteroscopy

Rigid ureteroscopy has been used since the 1980s and was initially indicated for management of distal ureteral stones. The development of smaller semi-rigid ureteroscopes and more recently, flexible deflectable ureterorenoscopes, allows routine endoscopic evaluation of the entire urinary collecting system. Both rigid and flexible ureteroscopy are used for stone diagnosis and treatment, investigation of gross hematuria and positive urine cytology, fulguration of epithelial tumors and management of ureteral strictures, obstructed calices, and ureteropelvic junction (UPJ) obstruction (see Figure 2).

Indications for uteroscopic stone management include SWL failures, lower pole stones, obesity, musculoskeletal deformities such as scoliosis, coagulation disorders, associated obstruction, horseshoe or ectopic kidney, or as an adjunct to percutaneous nephrolithotomy (Busby & Low, 2004). Small stones in the lower ureter (less than 7 mm in diameter) can be extracted by a basket or forceps passed through a rigid scope that has been passed over a working guidewire or alongside a safety guidewire. If the lumen of the ureter is narrow, it can be dilated with a self-dilating (tapered) ureteroscope, by coaxial dilation that uses larger catheters sequentially placed over smaller ones, or by balloon dilation in which a balloon catheter is placed over a working wire and then inflated. Contraindications to this surgery would be large ureteral or intrarenal stones.

Larger ureteral and intrarenal calculi can be treated with electrohydraulic or laser intracorporeal lithotripsy to fragment the stone(s) prior to passage or removal. Electrohydraulic lithotripsy with smaller caliber 1.9 Fr probes allows success in fragmenting ureteral and renal stones with less morbidity. Laser lithotripsy using the holmium:yttrium-aluminum-garnet technology is the treatment of choice for ureteral stones for most urologists. The more expensive holmium laser also allows for tissue cutting and coagulation and has largely replaced the pulsed-dye laser. Lower ureteral stone removal is effective in almost 100% of cases and slightly less effective for upper ureteral stones.

Complications are rare; however, ureteral perforation can occur during manipulation of a guidewire or basket and can lead to extravasation of contrast dye or urine. Significant bleeding is rare during ureteroscopy, but can occur after more traumatic procedures or difficult stone extraction. Instruments can break during proce-
goes ureteroscopy includes care for patients who have undergone manipulation of the ureter. Other complications include thermal injury and ureteral avulsion. Ureteral avulsion is rare but is among the most serious complications of ureteroscopy. It can occur during basket extraction of large stones without prior fragmentation. Urine must be drained proximally through a percutaneous nephrostomy if avulsion occurs, and ureteral reconstruction is subsequently performed.

A 4.8 to 7.0 Fr pigtail ureteral stent is left indwelling for a minimum of 48 hours after routine ureteroscopy. This stent helps facilitate urine flow and prevents edema from causing obstruction or ureteral colic that may occur with passage of a stone or clot. Stents range in length from 8 cm to 30 cm, and most are made of polyurethane. They generally need to have a hydrophilic coating to ease insertion, biodurability to resist degradation, biocompatibility with the patient’s body, and are radiopaque for radiographic visualization (Brownlee, 1999). Most stents are coated with a substance such as phosphoryl choline, a naturally occurring substance that alters the surface of red blood cells to reduce the risk of encrustation (Tolley & Segura, 2001). Some stents have an attached “suture” that allows easy removal by the patient.

Nursing care. Patients should be assessed preoperatively for history of stone disease, allergies to contrast dye, and sensitivity to shellfish. Equipment should be inspected in advance and disposable items such as graspers, baskets, and stents should be readily available. Antibiotics may be administered during the perioperative period. Anticoagulated patients may not need to discontinue their medications. Postoperative care for patients who have undergone ureteroscopy includes instruction to strain all urine for stone fragments, direction regarding suture care if it is externalized, and information about diet, medications, and drinking fluids.

Patients should be advised that symptoms of dysuria, terminal hematuria, and flank discomfort with urination can be expected. This is due to the fact that the stent interferes with the ability of the ureter to prevent reflux of urine, because the stent is positioned through the ureteropelvic junction. Patients who complain of discomfort from stents can be instructed to try a hot bath; they may also be prescribed antispasmodics and/or anti-inflammatory medication.

Percutaneous Nephrolithotomy

Endoscopic or intracorporeal management of stones through a percutaneous tract into the renal collecting system is called percutaneous nephrolithotomy (PNL). This technique was developed in 1975 by Fernstrom and Johanson (Tolley & Segura, 2001). It can be used for most renal and proximal ureteral stones (such as stones within the lower pole calyx, within a calyceal diverticulum or a staghorn calculus) but is used mostly for large stones (>2 cm) that are not easily managed by SWL or ureteroscopy, and as a salvage procedure for failed SWL.

A percutaneous nephrostomy tract is established under local anesthesia or intravenous sedation through an upper, middle, or lower pole posterior calyx under fluoroscopic or ultrasound guidance. A recent survey showed that only 11% of urologists obtained percutaneous access alone; in about 90% of cases, the tract is established by the attending radiologist (Bird, Fallon, & Winfield, 2003). The patient is placed in a prone, semi-prone, or flank position. A guidewire is then passed and the tract is dilated with graduated plastic dilators or a balloon dilator. A hollow plastic sheath is placed through the tract through which a rigid or flexible nephroscope is passed (see Figure 3). Stones less than 1 cm in size can be manually extracted through the plastic sheath using a grasping forceps.

The surgical procedure itself is commonly performed under general anesthesia. If the stones are larger than 1 cm, intracorporeal lithotripsy using ultrasonic, electrohydraulic, or laser lithotripsy is performed. Ultrasonic lithotripsy is used for large renal stones through a rigid scope. A recent review by Leveillee and Lobik (2003) showed that ultrasonic lithotripsy is preferred by urologists when using rigid scopes with a high fragmentation rate and 94% stone-free rate. Ultrasonic lithotripsy is the procedure of choice for fragmentation of large stones during PNL. Occasionally, a staged procedure is required for large stones in which ultrasonic lithotripsy may serve to debulk the stone burden which can then be treated with SWL.

Electrohydraulic lithotripsy (EHL) is reserved for fragmentation of very hard stones or those not within reach of the ultrasound rigid scope. More commonly, electrohydraulic lithotripsy is used extensively for bladder stones, but EHL can fragment all types of urinary calculi including hard cystine, uric acid, and calcium oxalate monohydrate stones. Unfortunately, EHL cannot efficiently remove stone fragments and the particles need to be washed out during intraoperative irrigation, or grasped with forceps. Pneumatic lithotripsy, on the other hand, produces the least amount of urothelial injury and it is considered among the most efficient form of intracorporeal stone fragmentation.

Laser lithotripsy is used similarly to EHL, but mostly is used for retrograde ureteroscopic fragmentation of calculi. Holmium:YAG laser lithotripsy is the preferred method when using flexible endoscopy, and is able to fragment...
all stone types with a nearly 100% stone-free rate (Leveillee & Lobik, 2003).

Once the stone is removed, inspection for residual stones is performed under fluoroscopic guidance. A nephrostomy tube that can be from 22.0 to 26.0 French is usually left in place temporarily to ease re-instrumentation if needed, to tamponade bleeding, and to allow proper drainage of urine. Tubeless PNL has been used for many years in select cases, and a recent study suggested that “tubeless” PNL, in which no nephrostomy tube is placed postoperatively, can be used in patients with minimal to moderate stone burden without increased complications (Limb & Bellman, 2002).

Minor complications occur in 11% to 25% of patients, while major complications occur in up to 7% (Menon & Resnick, 2002). The most significant complication of PNL is blood loss from damage to an intrarenal artery, with occurs in approximately 0.8% of cases, usually due to an arteriovenous malformation (Kessaris, Bellman, Pardalidis, & Smith, 1995). Symptoms include significant gross hematuria and management entails blood transfusion and arteriographic embolization of the damaged vessel.

Renal veins may be damaged as well. This is usually obvious during the procedure and is often treated by plugging the nephrostomy tube for 30 to 40 minutes which provides tamponade to the collecting system, and administration of mannitol or another diuretic concomitantly. Another complication is extravasation of the irrigating fluid. Differences of more than 500 ml between the volume of fluid infused and drainage collected through the tubes and on the drapes raise concerns about possible intravascular extravasation into the retroperitoneum. Irrigation should be performed using sterile saline to prevent hypovolemia, and this solution may be warmed as well.

Adjacent organ damage can occur, particularly to the colon, in about 1% of cases (Menon & Resnick, 2002), and less often to the duodenum, spleen, or liver. Colon perforation is suspected when intraoperative hematochezia, peritonitis, or sepsis is present, or when passage of flatus or feces from the nephrostomy tube occurs. This is usually managed by diverting colostomy and internally diverting urine using a double pigtail stent and Foley catheter. Every attempt is then made to separate the urinary and gastrointestinal tract to prevent fistula formation. Broad-spectrum antibiotics are given and radiographic studies through the colostomy are performed 7 to 10 days later to assure no communication (in other words, no fistula or sinus tract connection to the gastrointestinal and urinary systems) before the tube is pulled. Duodenal perforation can occur during right kidney PNL and is usually treated with placement of a nephrostomy tube and nasogastric tube to divert gastric secretions. Spleen injury may occur in cases of splenomegaly, and may lead to exploratory laparotomy and splenectomy. Risk of liver injury is rare but increases with hepatomegaly; treatment is usually conservative.

Nursing care. Patients scheduled for PNL should have urine cultures preoperatively to rule out urinary tract infection. Imaging studies are completed to verify stone location and kidney anatomy. If a struvite stone is suspected,
treatment for 2 weeks with a broad-spectrum antibiotic is recommended; antibiotics may also be recommended in patients with a history of recurrent urinary tract infections, or those requiring a postoperative indwelling stent.

Nonsteroidal anti-inflammatory medications (NSAIDS) and aspirin should be avoided for 10 to 14 days prior to procedure. Patients should have blood typed and screened. PNL is done under general or epidural anesthesia, and patients are usually hospitalized for 1 to 3 days and recover quickly. PNL is effective in up to 95% to 99% of cases, with lower success rates in patients with staghorn calculi or difficult access (Tolley & Segura, 2001). A nephrostomy tube may be left in place for 1 to 5 days, then removed and the site covered with a bulky bandage. Pain with the nephrostomy tube is lessened with a smaller size but may require narcotic medication. Good fluid intake is encouraged.

**SURGICAL MANAGEMENT**

**Open Lithotomy**

Only 1% to 5% of stones require an open procedure for removal. Open procedures have been largely replaced by SWL, ureteroscopy, and PNL due to decreased postoperative morbidity, more rapid recovery, and shorter hospitalizations and comparable success rates. In the past, obesity was an indication for open surgery, although development of longer nephroscopes makes percutaneous procedures possible in even the morbidly obese individual. One study of 223 patients showed no difference in duration of operation, hemoglobin levels, postoperative pain medication, length of hospital stay, or stone-free rates in obese (BMI > 30) versus normal weight patients (BMI < 25) undergoing PNL (Koo, 2004). Most often open lithotomy is reserved for patients who have failed SWL or PNL or who have abnormal anatomy. Branched or large stones may necessitate open surgical removal, while stones that may require multiple SWL or PNL procedures may be better managed with open surgery in select cases. Lastly, patients requiring partial or total nephrectomy for a nonfunctioning kidney, repair of ureteropelvic obstruction or stenosis, or in need of other nonurologic surgery may be candidates for open surgery.

**Nursing care.** Patients are hospitalized for 3 to 4 days. Oral and/or intravenous fluids should be increased to 3 L to 4 L daily if possible in the postoperative period. Urine output should be at least 0.5 ml/kg/hr (Bernier, 2005). Patients may require bladder irrigations and straining of all urine postoperatively. If a ureteral catheter is in place, output of at least 0.25 ml/kg/hr is expected. Ureteral catheters are kept open and may require irrigation when there is mucous, blood clots, and sediment in the urine. Irrigations are completed with 3 ml to 5 ml of sterile saline by gravity flow. Postoperative assessment includes monitoring bowel sounds and vital signs, and administration of antibiotics and pain medication as ordered. Patients may have pain requiring narcotic medication.

**Conclusion**

First-line therapy for urinary stones typically involves minimally invasive surgical procedures for obstructing stones that cause symptoms and do not pass spontaneously in a reasonable time. Treatment decisions are based upon suspected stone type, size, location, renal anatomy, and renal function. Morbidity, hospitalization, and cost are often reduced significantly with minimally invasive treatments such as shock wave lithotripsy, ureteroscopy, and percutaneous nephrolithotripsy; open surgical lithotomy is rare but indicated in select cases. Patients recuperate more quickly, have a quicker return to normal activity with the less-invasive surgical options that are available.

**References**


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