Extracorporeal Shockwave Lithotripsy

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Following its introduction in 1980, extracorporeal shockwave lithotripsy (ESWL) dramatically changed the management of renal and ureteral calculous disease. ESWL is a procedure in which renal and ureteral calculi are pulverized into smaller fragments by shock waves. These small fragments then can pass spontaneously. This noninvasive approach allows patients to be rendered stone-free without surgical intervention or endoscopic procedures.

All lithotripsy machines are composed of 4 basic components: (1) an energy source (the shockwave generator), (2) a focusing system, (3) an imaging or
localization unit, and (4) a coupling mechanism. Newer machines contain a patient treatment table.

**Shockwave generator**

All shock wave generators are based on the geometric principle of an ellipse. Shock waves are created at the first focal point of an ellipsoid (F1 within the half ellipse) and are directed to the second focal point (F2) within the patient. The focal zone is the area at F2 where the shockwave is concentrated.

Electrohydraulic, piezoelectric, and electromagnetic energy are the 3 methods of shockwave generation.

Electrohydraulic energy: This is the most commonly employed method of shockwave generation. An electrical discharge of a high-voltage current occurs across a spark-gap electrode located within a water-filled container. This discharge results in a vaporization bubble, which expands and immediately collapses, generating a high-energy pressure wave.

Piezoelectric energy: Hundreds-to-thousands of ceramic or piezo crystals set in a water-filled container are stimulated with a high-energy electrical pulse. This causes vibration or rapid expansion of the crystals, leading to a shock wave that can be propagated through the water.

Electromagnetic energy: An electrical current is applied to an electromagnetic coil mounted within a water-filled cylinder. The magnetic field causes an adjacent metallic membrane to be repelled by the coil, resulting in extremely rapid movement of the membrane, which produces a shaped shock wave.
Focusing systems

All shockwave lithotriptors require a focusing system in order to concentrate and direct the shockwave energy onto the stone, at F2, so that fragmentation can occur.

Electrohydraulic systems use the principle of the ellipse to direct the energy created from the spark-gap electrode. Piezoelectric systems arrange their crystals within a hemispherical dish, arranged so that the energy produced is directed toward one focal point. Electromagnetic systems use either an acoustic lens (Siemens system) or a cylindrical reflector to focus their waves.

Localization systems

Imaging is employed for stone localization and placement of the shock waves onto the calculus. In-line fluoroscopy is attractive in that images can be obtained during treatment without stopping; adjustments can be made to help ensure adequate placement. The 2 methods used to localize stones are fluoroscopy and ultrasound.

Fluoroscopy has advantages in that it can identify both renal and ureteral calculi and can help quantify migrating fragments. Disadvantages of fluoroscopy include the use of ionizing radiation and the inability to visualize radiolucent or minimally radiopaque stones. The administration of intravenous contrast during treatment may be useful in localizing stones with fluoroscopy. Other visualization techniques include using a ureteral catheter placed prior to the procedure so that contrast can be injected directly into the renal pelvis when necessary. If a double-J stent is present, contrast can be instilled into the
bladder via a catheter. This contrast then refluxes into the stented renal unit to help visualization.

Ultrasound allows visualization of both radiopaque and radiolucent renal stones without the need to administer intravenous contrast in addition to fluoroscopy. It also allows real-time monitoring of the lithotripsy process. Although it has the advantage of no ionizing radiation exposure, ureteral calculi often are very difficult to localize with sonography.

**Coupling mechanisms**

A coupling system is needed to transmit the energy created by the shockwave generator and pressure wave to the skin surface and through body tissues to reach the stone. Traditionally, this was accomplished by placing the patient in a large water bath (eg, the early-generation machine; Dornier HM3). In newer second-generation and third-generation lithotriptors that are commonly employed today, this cumbersome mechanism has been changed to the use of small pools of water or water-filled cushions with a silicone membrane to provide air-free contact with the patient's skin.

**History of the Procedure:**

**Evolution of shockwave lithotriptors**

The Dornier HM3 was the first shockwave lithotriptor employed in the United States. It has become the criterion standard when compared to newer devices. It is based on an electrohydraulic shockwave generator that, when fired in an ellipsoid, directs energy to the F2. It originally was designed to create shock waves to test supersonic
aircraft parts.

By placing the patient and generator in a water bath, the shock waves easily pass through tissue and are focused on a given stone. Localization is based on biplanar fluoroscopy. The Dornier HM3 can be employed to treat stones throughout the entire urinary tract.

Modifications to increase the applicability of the technology and to minimize anesthesia requirements have resulted in machines in which both renal and ureteral stones can be localized and treated.

The water bath employed with the Dornier HM3 has been replaced by a smaller generator and a water cushion that coapts to the patient in many of the newest designs, allowing shockwave propagation into tissue. With the new designs, patients can be treated in a variety of positions to help in localization and to maximize the effect.

Electromagnetic generators currently are the most common generators employed. They have smaller focal zones than the Dornier HM3 and, as such, require less anesthesia. While they do produce acceptable pressure waves, the smaller zones require superior imaging to precisely place the shock waves. Thus, the newer shockwave generators have less margin for error and require better imaging for localization.

The combination of ultrasonic and fluoroscopic localizing in the same machine is preferred in the newer-generation machines. This allows for the limitations of each modality to be compensated by the other. Ultrasound is especially useful for
radiolucent renal calculi, while ureteral stones are localized efficiently with pulsed-progressive fluoroscopy.

**Pathophysiology:** Fragmentation occurs when the tensile strength of a stone is overcome by the force of shock waves. Fragmentation is produced by direct force, erosion, or cavitation.

Direct fragmenting force uses shock waves to hit the anterior surface of stone and split the calculus.

Shock waves reflected off the stone return in the direction of the generator (the tensile component). The rest proceed through the stone (compressive component) and create a pressure gradient that fragments by erosion.

Cavitation is caused by shock waves that produce gaseous bubbles in a liquid medium. The bubbles collapse explosively, creating microjets that fracture and erode the calculus. This process can be noted on real-time sonography during treatment, and it appears as swirling fragments and liquid in the focal zone.

The current treatments available for renal and ureteral calculi include conservative management (waiting for spontaneous passage), ESWL, endoscopic techniques (rigid and flexible ureteroscopic lithotripsy), and percutaneous treatments.
The American Urologic Association Stone Guidelines Panel has identified ESWL as a potential first-line treatment for both proximal and distal ureteric stones and for renal stones smaller than 2 cm. However, complex presentations frequently are treated best endoscopically.

**Contraindications:** Acute urinary tract infection, uncorrected bleeding disorders, pregnancy, sepsis, and uncorrected obstruction distal to the stone all are considered absolute contraindications.

Several factors are considered relative contraindications to treatment. They include the following:

- Compromised mental status must be considered, including the ability to cooperate and understand the procedure.

- Weight greater than 300 lb prohibits proper shockwave placement onto the calculus because the distance between F1 and F2 may exceed the specifications of the lithotriptor. In these patients, simulation on the lithotriptor gantry may be performed to determine whether treatment is technically feasible.

- Patients with orthopedic or spinal deformities, renal ectopy, and/or renal malformations (including horseshoe and pelvic kidneys) may present difficulties in appropriate positioning for
ESWL. In addition, associated abnormalities of intrarenal drainage may prohibit prompt clearance of the fragments created by shockwave lithotripsy.

- Most preexisting pulmonary and cardiac problems can be managed with appropriate anesthesia. Dysrhythmias are common during lithotripsy and are controlled by cardiac gating. In this setting, the shock wave is discharge by the R wave in the cardiac cycle, which prohibits most tachyrhythmias.

- Patients with cardiac pacemakers may be safely treated with ESWL, but they require special attention and consideration. The assistance of a cardiologist in this setting often is helpful.

- Patients with preexisting hypertension have been found to have an increased incidence of posttreatment perirenal hematoma.

- Patients with gastrointestinal disorders, in rare circumstances, may experience posttreatment exacerbation.

Patients must discontinue anticoagulants, such as coumadin, in sufficient time for clotting factors to return to normal. Aspirin-containing products and nonsteroidal anti-inflammatory agents should be discontinued for 7-10 days prior to treatment to allow platelet function to normalize.
Lab Studies:

- Laboratory studies are performed prior to this procedure to ensure that the patient does not have a concurrent urinary tract infection and that the patient does not have a bleeding disorder. Proper preparation in these settings minimizes the risk of intraoperative and postoperative complications.

- Urinalysis, urine culture

- CBC count, including prothrombin time and activated partial thromboplastin time

Imaging Studies:

- Intravenous pyelogram

- Renal sonography

- Noncontrast CT scan

Other Tests:

- Electrocardiogram if patient is older than 50 years

Preoperative details: Several factors related to the stone, including size, number, composition, and location, may have an effect on the outcome of ESWL.

Size

As stone size approaches 2 cm, success with ESWL decreases markedly. The American Urological Association Guidelines Panel recommends that stones larger than 2 cm should not be treated with ESWL.
ESWL works best for moderately sized renal calculi not associated with obstruction. Infected stones are not effectively treated with ESWL monotherapy, and other treatment options should be employed. In addition, without secure drainage (ie, ureteral stent placement), posttreatment obstruction from fragment migration may lead to acute renal colic and sepsis if the stone burden is infectious in composition. However, note that most upper urinary tract calculi are not composed of infectious material (ie, struvite).

**Stone composition**

Calculi composed of calcium oxalate dihydrate, magnesium ammonium phosphate, and uric acid fragment readily with ESWL. Uric acid calculi, due to their radiolucency, require the use of either ultrasound or a contrast agent with fluoroscopy for proper localization and precise shockwave placement.

Calcium oxalate monohydrate and certain forms of calcium phosphate stones (eg, brushite) are more difficult to fragment with ESWL. Cystine stones often are resistant to fragmentation with ESWL.

**Stone location**

- Renal calculi
  - The dependent position of the lower-pole calyces appears to hinder stone passage, and not surprisingly, stone-free rates are significantly decreased for lower-pole stones treated with ESWL. Lower-pole stones larger than 2 cm in diameter treated with shockwave lithotripsy are associated with a stone-free rate well below 10% and should be approached with different treatment modalities.
  - Stones in calyceal diverticula represent a unique surgical challenge. Most experts in the field of urologic stone management feel strongly that percutaneous nephrolithotomy or ureteroscopic treatment are more efficacious than ESWL because not only is the stone burden
treated, but drainage of the obstructed portion of the collecting system also is improved with these interventions.

- Ureteric calculi
  - Stones located in the proximal and distal ureter are more successfully fragmented with ESWL than stones in the middle third of the ureter.
  - Middle-third ureteral calculi are harder to treat properly, owing to difficulties in localization due to the overlying bony pelvis.

**Stenting and extracorporeal shockwave lithotripsy**

Most experts now feel that ESWL should be a noninvasive procedure. The term ESWL monotherapy refers to the use of shockwave lithotripsy, frequently performed under minimal anesthesia, without endoscopic instrumentation. The placement of a ureteral stent cystoscopically often requires a greater degree of anesthetic and obviously is invasive. Stents are placed to ensure upper urinary tract drainage and to prevent transient obstruction from fragment migration post-ESWL. In addition, they can be used to help in localization of ureteral calculi or to "push back" a stone from the ureter into the kidney, where it can be more easily treated with a higher degree of success.

Currently, the endoscopes employed to treat calculi ureteroscopically are approximately the same diameter as the ureteral stents and infrequently are associated with negative sequelae. In addition, the success rates associated with endoscopic lithotripsy exceed those with ESWL. For these reasons, the author feels that if a ureteral stent is required prior to ESWL, endoscopic lithotripsy may be a more definitive and particularly efficacious treatment.

The traditional general indications for ureteral stenting prior to ESWL are (1) large dense stone burdens (>15 mm), (2) completely obstructing and/or impacted stones, and (3) poorly visualized stones.
**Intraoperative details:** During shockwave lithotripsy, the natural movement of the kidney during respiration moves the stone burden in and out of the focal zone (ie, F2). Real-time in-line sonographic imaging is particularly useful because small adjustments can be made continuously during treatment to ensure that the majority of shock waves are placed on the calculus. Because ureteral stones infrequently are localized with ultrasound, this is useful only for renal calculi.

Pulse-progressive fluoroscopy also can be used to help localize and maintain the stone burden within the focal zone, while minimizing the quantity of ionizing radiation exposure.

**Postoperative details:** After ESWL, most patients have transient hematuria and intermittent colic as fragments pass. Proper hydration and analgesia are essential during the immediate postoperative period.

Fever is an uncommon symptom after treatment and may reflect complete ureteral obstruction. The word *steinstrasse* (ie, stone street) was used by the German pioneers of ESWL to refer to a group of fragments impacted in a segment of ureter. This so-called stone street may clear with supportive measures or may require endoscopic intervention if upper urinary tract obstruction persists.

Postoperative imaging is based on radiographs and sonography to quantify residual stone burden and to define any hydronephrosis. Imaging usually is obtained within the first month postoperatively. Obviously, if the patient is symptomatic, it is obtained sooner.

**Follow-up care:** For excellent patient education resources, visit eMedicine's [Kidneys and Urinary System Center](https://www.emedicine.com/). Also, see eMedicine’s patient education article [Kidney Stones](https://www.emedicine.com/).
Renal complications

Perinephric, subcapsular, and/or intranephric hematoma: These can be associated with severe pain, ileus, and, infrequently, shock or hypotension. They rarely require transfusion, embolization, or even nephrectomy.

Hematuria: This is noted in the majority of patients and clears within the first few days postoperatively. Passage of many clots and clot urinary retention occur infrequently and should prompt additional imaging to assess a retroperitoneal and/or renal source.

Sepsis: This is infrequent if preoperative urine is sterile.

Steinstrasse: If asymptomatic and nonobstructing, the patient is monitored closely with serial imaging. If obstructing, infected, or symptomatic, percutaneous nephrostomy or ureteroscopic treatments with stenting are employed to ensure drainage.

Hypertension: This is unusual, but it can result when a large perinephric hematoma occurs.

Renal atrophy: Although infrequent, it can occur if the patient has renal vascular or severe atherosclerotic disease. In addition, those patients with underlying renal parenchymal disease may be at a higher risk.

Others possible complications

These may include (1) lung complications (ie, hemoptysis), (2) pancreatitis, (3) splenic hematoma, (4) elevated liver functions (transient), and (5) biliary colic with inadvertent fragmentation of adjacent biliary stones.
Shockwave therapy is useful in treating urinary calculi. The mechanism of action is based on pressure waves that, when focused onto a stone, fragment it into more easily passable pieces. Controversy exists with some of the newer shockwave generators. The smaller focal zone and newer tabletop designs increase the indications for treatment and lower the anesthetic requirements, but they may decrease the overall efficacy of the treatment.

The newest generators require precise localization, with little margin for error in light of the greatly reduced focal zones. The focal zone of the original Dornier HM3 exceeded 2 cm, while most new electromagnetic generators have focal zones that average only 6 mm. This means that the operator must be more attentive and must compensate for respiratory movements during treatment. On a positive note, this also means that less renal parenchyma is affected or damaged during the treatment.

Other experimental applications of shockwave generators include biliary and pancreatic duct stone lithotripsy and treatment of various forms of joint disease associated with calcium deposition.

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