Shock Wave Lithotripsy for Renal and Ureteric Stones

Christian Bach, Noor Buchholz*

Department of Urology, Barts and The London NHS Trust, London, UK

Abstract

**Objective:** We provide a comprehensive overview of the main aspects of shock wave lithotripsy (SWL) for renal and ureteric stones.

**Evidence acquisition:** We reviewed current literature, concentrating on high-quality reviews in international journals. In addition, the latest European Association of Urology guidelines and standard textbooks were consulted.

**Evidence synthesis:** SWL can treat >90% of stones in adults and has revolutionized the treatment of urolithiasis. Despite the progress of minimally invasive endourologic procedures, SWL still contributes to >50% of all stone treatments worldwide.

With modern machines, stone-free rates of the initial Dornier HM3 have not been reached again. Apart from stone size, multiple predictive outcome factors like stone composition, position, and renal anatomy have been identified, and indications have been refined. Interestingly, a growing number of nonurologic indications for SWL such as stimulating re-epithelization and improving myocardial function, have been reported recently.

Furthermore, treatment protocols have been optimized by lowering shock wave rate, improving coupling, applying abdominal compression, power ramping, and postoperative medical expulsion therapy. New promising developments are twin-head and tandem-pulse shock wave generators. Automated localization and acoustic tracking and feedback systems have been developed with the potential to improve stone disintegration, to limit radiation, and to avoid overtreatment and complications.

**Conclusions:** SWL is a safe and well-established procedure that still plays an important role in the treatment of upper urinary tract stone disease. To achieve optimal results, the refined indications need to be respected and patients need to be carefully selected. Treatment protocols need to be optimized. Novel promising technical developments are upcoming, and there is growing interest in shock wave therapy from other specialties. SWL is a substantial part of urology that every urologist should learn to master during his or her training.

© 2011 European Association of Urology. Published by Elsevier B.V. All rights reserved.

* Corresponding author. Department of Urology, Barts and The London NHS Trust, West Smithfield, London, EC1A 7BE, UK. Tel. +44 20 3465 6410; Fax: +44 20 3465 5413.
E-mail address: noor.buchholz@bartsandthelondon.nhs.uk (N. Buchholz).

1569-9056/$ – see front matter © 2011 European Association of Urology. Published by Elsevier B.V. All rights reserved. doi:10.1016/j.eursup.2011.07.004

1. Introduction

Shock wave lithotripsy (SWL) has revolutionized the treatment of upper urinary tract (UUT) calculi. Shortly after its introduction in 1983, it became widely accepted as the primary treatment modality for the majority of stones and quickly replaced open surgery. Further evolution of the lithotripters has led to sophisticated third- and fourth-generation machines that are user-friendly, safe for the patient, and adaptable for a variety of endourologic
applications. Treatments are performed not only by doctors but also by highly specialized technicians (Table 1).

Over time, the limitations of SWL have become evident, as the stone-free rate of the initial Dornier HM3 (Dornier MedTech Europe, Wesseling, Germany), introduced in 1984, has never been reached again with the new machines. This realization resulted in a redefinition of indications; apart from stone size, multiple parameters (ie, number, composition, localization, urinary tract anatomy, and patient’s comorbidities) have to be considered to achieve a favorable clinical outcome.

Further effort was made to optimize treatment protocols by lowering shock wave frequency, using power ramping, and improving coupling. Additional postoperative measures such as medical expulsive therapy (MET) and percussion, inversion, and diuresis have been shown to contribute to a maximized stone-free rate (Table 2).

The development of alternative minimally invasive stone surgery such as ureterorenoscopy (URS) and percutaneous nephrolithotomy (PCNL) progressed much slower but caught up with SWL rapidly in recent decades. With these approaches, stone-free rates are considered to be slightly better, albeit with more invasive procedures. Whereas URS and PCNL are minimally invasive, SWL can be regarded as a “no-touch” procedure, making it especially interesting in a disease with such a high recurrence rate like urolithiasis.

Worldwide, there is a trend toward more active management of even small stones and a shift toward endourologic procedures. These changes are triggered not

---

Table 1 – Contraindications for shock wave lithotripsy

<table>
<thead>
<tr>
<th>Absolute contraindication</th>
<th>Pregnancies</th>
<th>Potential disruptive effect on fetus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative contraindications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleeding diatheses</td>
<td></td>
<td>• Correction 12 h before to 48 h after treatment</td>
</tr>
<tr>
<td>Uncontrolled urinary tract infections</td>
<td></td>
<td>• Careful postoperative monitoring</td>
</tr>
<tr>
<td>Arterial aneurism in the vicinity of the treated stone</td>
<td></td>
<td>• If not safe to discontinue: URS</td>
</tr>
<tr>
<td>Anatomic obstruction distal of the stone</td>
<td></td>
<td>After correction:</td>
</tr>
<tr>
<td>Severe obesity, exceeding weight specification and penetration depth of shock wave</td>
<td></td>
<td>Perioperative AB continued for at least 4 d postoperatively</td>
</tr>
<tr>
<td>Low pain threshold</td>
<td></td>
<td>Rupture and migration of atherosclerotic plaques possible</td>
</tr>
<tr>
<td>Skeletal malformations making positioning and targeting impossible</td>
<td></td>
<td>Correct before treatment</td>
</tr>
</tbody>
</table>

AB = antibiotics; URS = ureterorenoscopy.

---

Table 2 – Complications of shock wave lithotripsy [21]

<table>
<thead>
<tr>
<th>Residual fragments</th>
<th>Steinstrasse</th>
<th>4–7%</th>
<th>Predisposing factors:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regrowth of residual fragments</td>
<td></td>
<td>21–59%</td>
<td>• Stone size and number</td>
</tr>
<tr>
<td>Renal colic due to passing fragments</td>
<td></td>
<td>2–4%</td>
<td>• Stone composition</td>
</tr>
<tr>
<td>Infectious complications</td>
<td>Bacteriuria in noninfection stones</td>
<td>7.7–23%</td>
<td>• Position</td>
</tr>
<tr>
<td>Sepsis</td>
<td></td>
<td>1–2.7%</td>
<td>• BMI &gt;30</td>
</tr>
<tr>
<td>Macrohemituria</td>
<td></td>
<td>Frequently</td>
<td>• Shock wave rate and energy</td>
</tr>
<tr>
<td>Renal hematoma, symptomatic</td>
<td></td>
<td>&lt;1%</td>
<td>• Experience of operator</td>
</tr>
<tr>
<td>Renal hematoma, asymptomatic</td>
<td></td>
<td>4–11%</td>
<td>Predisposing factors:</td>
</tr>
<tr>
<td>Cardiac dysrhythmia</td>
<td></td>
<td>11–59%</td>
<td>• Positive urine culture</td>
</tr>
<tr>
<td>Morbid cardiac events</td>
<td></td>
<td>Case reports</td>
<td>• History of recurrent UTIs</td>
</tr>
<tr>
<td>Bowel perforation</td>
<td></td>
<td>Case reports</td>
<td>• Infection related stones</td>
</tr>
<tr>
<td>Hematoma of liver, spleen</td>
<td></td>
<td>Case reports</td>
<td>• Previous instrumentation</td>
</tr>
<tr>
<td>Hypertension</td>
<td></td>
<td>No evidence</td>
<td>• Indwelling catheters, stents, nephrostomies</td>
</tr>
</tbody>
</table>

BMI = body mass index; UTI = urinary tract infection.
only by the effectiveness and side effects of the respective treatment modalities but also by the need to fill operation theater capacities, to utilize expensively bought equipment, to meet remuneration strategies in the health system, and to appease high pressure for the patient to return to work quickly.

2. **Historical background**

The concept of SWL is a classic technology spin-off from a military development. Originally developed in Russia in 1950s, SWL was rediscovered during investigation of pitting on the wings of the Lockheed F-104 Starfighter at mach 2. The German aircraft company Dornier found that impinging rain drops led not only to local erosion but also to changes in the surrounding molecular structure. The explanation was found in the supersonic shock waves generated by colliding raindrops [1]. Extensive clinical research between Dornier and the Ludwig Maximilians University in Munich, Germany, finally led to the first human treatment [2].

This first human SWL treatment was performed in 1980 by Chaussy et al in the Klinikum Großhadern in Munich using a prototype Dornier HM1 (Human Model 1) lithotriptor on a patient with a kidney stone [3]. The first serial-type machine, the Dornier HM3 (Human Model 3), was installed in this hospital in 1983, and the first exported lithotripter went in 1984 to the Methodist Hospital in Indianapolis, Indiana, in the United States [4].

Thereafter, worldwide dissemination of lithotripters began, leading to a revolution in stone treatment. Five years after its introduction, SWL was already accepted as the primary mode of treatment for nearly all nonpassable UUT calculi except staghorn stones, nephrocalcinosis, and diverticular stones. It had widely replaced open surgical stone removal in such places where SWL was available [5].

With the HM3, treatment was complicated. To achieve optimal coupling, the patient was placed in a large basin filled with degassed, deionized water and known as “the most expensive bathtub in the world.” Because these initial procedures were very painful, they had to be conducted under general anesthesia. Further technical developments made the machines more user friendly and the treatments less painful. Coupling is now achieved through a water-filled cushion covered with ultrasound jelly. In addition, by modifying the shock wave generators, the treatment has become less painful, and analgesia rather than anesthesia is usually sufficient [6]. The compromise, however, is that none of these newer machines reached the original HM3’s excellent stone-free rates of about 90% in uncomplicated non–lower-pole stones [7].

It is difficult to exactly determine the current proportion of SWL in treatment of urolithiasis worldwide. Numbers reported range from 37% in 2007 from a German primary urolithiasis center [8] to 70–80% in 2000 in the United States [9]. Despite a shift toward endourologic procedures, one can estimate that about 50% of all stone treatments worldwide today are performed by SWL [10].

3. **Technique, physics, and mechanism of stone fragmentation**

All lithotripters consist of a shock wave generator, a mechanism to focus the shock waves on a target, a stone localization system, and a coupling medium [11].

The shock wave generator produces concentric, supersonic shock waves. During its passage through the tissue, the widespread and as yet unfocused single shock waves have low energy and therefore travel without causing tissue damage. At the focal point, the shock waves meet, and the energy builds up to its peak level and is capable of breaking objects as hard as urinary stones but also can produce side effects such as tissue damage [1,7].

A typical shock wave is an acoustic pressure wave of short duration (<10 microseconds) with a peak pressure up to 100 megapascals (MPa) during the compressive phase, which is followed by a tensile phase with negative pressure. Different parameters like acoustic energy, energy flux density, and effective energy can be calculated from the shock wave model. It remains unclear which parameters could reliably predict stone fragmentation and tissue damage [12].

Stone fragmentation is caused by shock wave–induced stress. Mechanisms include tear and shear forces [3], cavitation [13], spallation [14], quasi-static squeezing [15], and dynamic squeezing [16]. These mechanisms lead to cracks in the structure of the stone, and, as a result of repetition, these cracks grow and accumulate over time, finally leading to stone disintegration [17].

3.1. **Generating shock waves**

The original Dornier HM3 (out of production for >20 yr) was equipped with an electrohydraulic shock wave generator. It had a broad focal width of about 12 mm, making hitting the stone and transmitting energy easy. With a relatively low peak pressure of 40 MPa, minimal collateral damage was caused. The narrow aperture led to high energy delivery at skin level, making the treatment painful (Fig. 1).

Further development led to other types of shock wave generators with enhanced aperture to distribute the energy over a larger skin surface to cause less pain. Consequently, the focal zone became smaller, sometimes around 3–6 mm. Peak pressures rose up to 160 MPa. These newer machines had higher retreatment rates and a higher incidence of adverse effects [18].

In current lithotripters, four different principles of shock wave generation are applied: electrohydraulic, electromagnetic, piezoelectric, and electroconductive. Electrohydraulic systems produce a spherical shock wave by an underwater spark discharge between two electrodes. An ellipsoid reflector focuses the wave. These systems have high disintegrative capacity but cause considerable pain. A further disadvantage is the high variability of shock waves observed from pulse to pulse as a result of electrode wear, making frequent replacement necessary [7].

Electromagnetic generators produce shock waves as a plain or cylindrical metallic membrane is moved by an
electrical impulse, comparable to a loudspeaker. An acoustic lens or a parabolic reflector focuses the shock waves, which are powerful and consistent. Compared with electrohydraulic systems, the wider aperture makes treatment less painful but the smaller focal point leads to increased tissue damage [7].

In piezoelectric shock wave sources, multiple ceramic elements produce small impulses. They merge in the focal point in the center of a sphere as an energy shock wave with high peak pressure. The shock waves are very constant. A very large aperture leads to a wide area of entrance over the skin and creates a pain-free treatment. A disadvantage is the low overall energy delivered to the stone due to the very narrow focal point, leading to a higher retreatment rate [19].

The electroconductive generator (EDAP TMS, Vaulx-en-Velin, France) is a derivate of the electrohydraulic principle. Its electrode is encapsulated in a highly conductive electrolyte solution, making a shorter interelectrode distance feasible. This leads to less electrode wear and offers the advantage of powerful and highly reproducible shock waves [12].

3.2. Imaging

Effective high-quality visualization of the stone for initial localization and monitoring during treatment is crucial for the success of SWL. The more precisely the stone can be targeted, the more likely it is to be fragmented and the less collateral tissue damage is to be expected. In modern lithotripters, digital fluoroscopy and advanced in-line ultrasound are both available. Even with recent high-end systems, it remains challenging to identify calculi < 5 mm in diameter. Still, there is an ongoing debate about which imaging systems provide the best results [12].

3.3. Fluoroscopy

Fluoroscopy is the current standard for stone localization. Although the original Dornier HM3 was expensively equipped with two x-ray systems installed at a 90° angle, modern machines have the fluoroscopy unit mounted on an isocentric C-arm [7]. Many urologists favor fluoroscopic imaging because they are familiar with it. It allows visualizing even ureteric stones, and it can be used with iodinated contrast agents, which can be applied antegrade, retrograde, or intravenously [7,20]. The disadvantages of fluoroscopy are the exposure of patients and staff to ionizing radiation and the inability to visualize radiolucent calculi without radiographic contrast agents [1,7]. X-ray systems also require more space and intensive maintenance as well as specially trained staff and shielded treatment rooms.

3.4. Ultrasound

Ultrasound can localize radiolucent calculi and has the advantage of real-time imaging without x-ray exposure at a much lower cost than fluoroscopy [19]. However, a highly trained operator is needed. Many urologists are not familiar with ultrasound, and only kidney and distal ureteric stones can be visualized. Stones can also be obscured by an indwelling ureteric stent [7].

3.5. Combined systems

Ideally, the advantages of both localization modalities will be combined in a lithotripter. The combination of fluoroscopy and ultrasound in a modular design with detachable units creates versatile multipurpose machines that can be used not only for lithotripsy but also for a broad range of endourologic applications [1].

4. Indications

The treatment modality should be individually tailored to every patient, and it has to be taken into account that the choice of the appropriate treatment modality for an individual case depends not only on the guidelines but also on the patient’s preference, the available equipment and infrastructure, the local health system and reimbursement policies, and the surgeon’s expertise.
4.1. **Kidney stones**

According to the European Association of Urology (EAU) guidelines on urolithiasis, active stone removal is recommended for kidney calculi >6–7 mm. If symptomatic, even kidney stones <6–7 mm can be considered for treatment. In patients with normal renal anatomy, for non–lower-pole kidney stones <20 mm, SWL in situ is recommended as first-line therapy. The only exceptions are uric acid stones, for which oral chemolitholysis is recommend. As for lower-pole stones, stone-free rates for SWL are reduced, so alternative treatments (PCNL, URS) should be considered (see section 7.2, stone position).

4.2. **Ureteric stones**

For ureteric stones, treatment recommendations again depend on stone size. SWL in situ is recommended for upper ureteric stones <10 mm, and SWL or URS are recommended for bigger stones. Distal ureteric stones <10 mm should be approached with either SWL or URS and preferably with URS for stones above that size. For uric acid stones, stenting and oral chemolitholysis is the preferred option.

4.3. **Further indications**

Residual fragments after PCNL (sandwich therapy), encrusted stents and catheters, Peyronie’s disease, bile duct, salivary gland stones, and a variety of musculoskeletal disorders are further indications for SWL. In an interesting development, shock wave therapy has been shown to stimulate angiogenesis and re-epithelization as improving ventricular function in patients with ischemic heart disease [22–24].

5. **Contraindications**

Pregnancy remains the only absolute contraindication due to a potential disruptive effect on the fetus; however, there are reports of patients undergoing SWL in the early stage of pregnancy without any detectable side effects or malformations for the later-delivered fetus [25]. Female and male fertility seem not to be affected by SWL [26]. Uncorrected bleeding diathesis is a relative contraindication, increasing the risk of subcapsular or intrarenal hematomas and persistent hematuria with clot formation and resulting renal colics. Preoperative correction of coagulation should follow the same principles as applied for small to intermediate surgical interventions, and coagulation should be compensated at least 12 h before and until 24 h after the intervention [21]. Antiplatelet drugs should be stopped at least 1 wk before treatment [1]. In cases where coagulation-altering medication cannot be discontinued safely, (flexible) ureteroscopy for stone removal is the preferred alternative treatment option [21]. Renal or aortic aneurisms are relative contraindications, as fragmentation and migration of arteriosclerotic plaques or even rupture of the aneurysm could be provoked [1]. However, data show that patients with these comorbidities can be treated safely [27].

In patients with acute urinary tract infections (UTIs), the infection should be treated first to prevent dissemination of bacteria and endotoxins into the tissue and the body.

Obstruction distal to the stone can prevent passage of fragments. Possible causes include calyceal neck stenosis, renal calyceal diverticula, ureteropelvic junction stenosis, ureteric strictures, benign prostatic enlargement, and urethral and meatal strictures. If not correctable, these conditions may represent contraindications for SWL treatment [28].

Further contraindications are patients with musculoskeletal malformations that make positioning or proper coupling impossible [29]. In severe obesity, skin–stone distance can exceed the penetration depth of the shock wave or patient weight can exceed manufacturer specifications for safe load of the table [30]. Due to a low pain threshold, some patients might not be suitable for treatment without anesthesia; others are not able to lie still during the procedure [1]. If facilities are in place for in-patient treatment under general anesthesia or sedation, this can be considered. Otherwise, these patients may undergo alternative treatments.

6. **Complications of shock wave lithotripsy**

Overall complication rate for SWL is lower than for URS or PCNL [21]. The main risks are renal colic and UTIs. However, patients need to be made aware of symptoms that make reattendance necessary, and an informed consent needs to be signed [1].

6.1. **Retained or obstructing residual fragments**

The ureter has a limited capacity for discharging stones. Larger residual fragments after SWL can cause renal colic and ureteral obstruction. In the extreme, this may lead to the formation of a steinstrasse, the German term for “stone street,” which is defined as an agglomeration of stone fragments stuck in the ureter. Usually, smaller fragments are held up and consolidated behind a larger lead. Predisposing factors for failure of fragmentation are stone size, number, composition and localization, and renal morphology as well as shock wave rate and energy [26].

Results of SWL are operator dependent; the best stone-free rates are obtained by the operator who treats the greatest number of patients [31].

Residual fragments <5 mm are sometimes called *clinically insignificant fragments* and have a high chance of passing spontaneously without further treatment. However, persistent UTIs, symptomatic episodes, and stone regrowth with the need for treatment has been reported in 21% and up to 59% [21]. These findings suggest that *clinically insignificant fragments* is a misnomer and should be avoided [32].

Realizing the limitations of SWL in such patients with a high stone burden can prevent complications related to obstructing or residual fragments if acted on preventively [26].
6.2. Infectious complications

Facilitated by tissue damage and vascular disruption, bacteria and endotoxins from the urine can enter the bloodstream during SWL. Likewise, bacteria released from infectious stones can be absorbed systemically. Consequently, bacteruria, bacteremia, UTI, urosepsis, perinephritic abscess formation, endocarditis, Candida and Klebsiella endophthalmitis, candida septicemia, miliari tuberculosis, and even septic death following SWL have been reported [33].

6.3. Tissue effect of shock wave lithotripsy

Tissue damage after SWL is based on vascular lesions caused mainly by cavitation and shear stress. It is dose dependent and related to the number, the energy level, and the total energy amount of the shock waves applied [34].

Macrophematuria is the most common clinical manifestation of renal trauma after SWL and usually resolves spontaneously after a few days [26].

Symptomatic kidney hematomas have an incidence <1%. However, routinely performed computed tomography (CT) or magnetic resonance imaging studies after treatment have shown an overall incidence of up to 4% [35]. Potential risk factors include bleeding diathesis, use of antplatelet drugs, obesity, diabetes mellitus, patient age, arterial hypertension, number and intensity of shock waves, and type of shock wave generator. Hematomas can be treated conservatively in most cases [26].

Renal function is impaired immediately after SWL, and glomerular filtration rate and renal plasma flow are reduced. These parameters normalize shortly after the treatment, and, to date, there is no proof of long-term kidney damage related to SWL [26]. Whether SWL treatment of kidney stones leads to a higher incidence of hypertension is controversial. Up to now, no randomized controlled trial has shown that SWL causes long-term changes in blood pressure [36].

Gastrointestinal injury following SWL treatment is rare. However, conditions like bowel or gastric ulcer, hematoma or perforation, liver and spleen hematomas, ureterocolic fistula formation, and pancreatitis have been reported in 1.81% [37].

Cardiac arrhythmias are common during ungated SWL, but a morbid cardiac event or biochemical evidence of myocardial damage is extremely rare [38]. In patients with cardiac pacemakers, treatment can be performed safely with adequate precautions in close cooperation with a cardiologist [26].

7. Predictive clinical outcome factors

SWL can treat >90% of UUT stones in adults [21]. However, there are patients for whom SWL is likely to fail and for whom other treatment options should be preferred. It is important to identify those patients. Such identification avoids unnecessary exposure of patients to shock waves and radiation and saves resources in the health care system [39].

7.1. Stone burden

The success rate of SWL decreases with stone size. For stones >20 mm, the stone-free rate has been reported to be <50%, thus SWL is not recommended [40]. It remains controversial whether measuring the largest diameter is sufficient or if a more dimensional approach with measurement of stone volume is required [41]. The number of stones is another important predictor of success. The more calculi are present, the worse the success rate [40].

7.2. Stone position

Lower-pole stones have shown a significantly lower clearance rate after SWL compared with PCNL [42]. One reason for this low stone clearance is gravity keeping stones in the depending portions of the collecting system. Infundibulopelvic angle >70°, infundibular length <3 cm, infundibular width >5 mm, and the presence of a single minor calyx are associated with favorable outcome [43]. For lower-pole stones between 11 and 20 mm, some authors recommend PCNL [44] or URS as less invasive alternatives [45]. For isolated stones <1 cm, no statistical difference in stone-free rate between SWL and URS has been shown [46].

7.3. Stone composition

Very hard stones like calcium monohydrate, cystine, and brushite stones show a low fragmentation rate. A non-contrast CT scan can help identify patients with those hard stones. For stones with a density >1000 Hounsfield units, an alternative treatment should be considered [7,39].

7.4. Renal abnormalities

Stone targeting in malrotated, horseshoe, or duplex kidneys is often difficult, and clearance is reduced. Repeat sessions are often necessary. The same principles apply as in normal kidneys, and for stones <20 mm, SWL is considered first-line therapy [21,47]. Simple cysts and renal abnormalities are not contraindications for SWL [1].

7.5. Obesity

Body mass index (BMI) >30 and skin-to-stone distance >9–10 cm have proven to be independent predictors of SWL failure [48,49]. Shock wave energy is reduced by 10–20% for every 6 cm of penetrated body tissue, and imaging is more difficult [1]. Furthermore, obese people have a higher risk of kidney hematomas. In these patients, URS is the more promising therapeutic option [21].

8. Best clinical practice and how to improve the success rate

8.1. Preoperative imaging

Adequate preoperative imaging is essential in predicting the outcome of SWL. To precisely assess stone burden,
position, skin-to-stone distance, and anatomy of the urinary tract, non–contrast-enhanced CT, preferably with coronal image reconstruction, is recommended. In patients with BMI $<$30, low-dose protocols should be used. If there are any doubts regarding the position of the stone in relation to the collecting system, contrast-enhanced CT with three-dimensional reconstruction or intravenous urography provides further information [21].

In addition to CT imaging, a preoperative plain x-ray is useful to update information about stone position in relation to surrounding structures.

8.2. Stenting prior to shock wave lithotripsy

Stenting prior to SWL should be considered in patients with large stone size ($>$20 mm) or with a solitary kidney to reduce complications caused by residual fragments. However, it does not prevent the formation of steinstrasse or the incidence of infective complications and might even lead to decreased stone clearance due to reduced ureteric peristalsis [21,26]. For ureteric stones, stenting is not routinely recommended but can provide anatomic orientation to facilitate localization of ureteric stones.

8.3. Antibiotic prophylaxis

No standard perioperative prophylaxis is recommended. Antibiotics should be given in cases of positive urine culture, a history of recurrent UTI, or infection-related staghorn or struvit calculi or instrumented at the time of SWL. Antibiotics should be continued for at least 4 d [1,33]. The EAU guidelines even recommend a prophylaxis for patients with indwelling catheters, stents, and nephrostomy tubes [21].

8.4. Pain management

General or regional anesthesia was required with first-generation lithotripters. Modern machines are optimized toward patient comfort. However, SWL is still not a pain-free procedure, and adequate analgesia is mandatory to achieve patient compliance and to avoid defocusing through involuntary patient movement and increased respiratory motion causing a reduced hit rate. Pain may also lead to an undesired rise in blood pressure. The pathogenesis of shock wave–induced pain is not yet clear. It seems to be caused by cavitation with formation and movement of the finest gas bubbles rather than by direct mechanical effects on nociceptive nerve endings [50].

Multiple drugs and techniques have been proven effective in analgesia. Most commonly used are orally or rectally administered nonsteroidal anti-inflammatory drugs (NSAIDs) and intravenously administered opioids. NSAIDs (eg, diclofenac 100 mg) have a good analgesic effect, especially when delivered rectally. Additionally, their action is anti-inflammatory and antiedematous, and they relax the ureteric wall (note: allergies, renal and hepatic insufficiency, digestive ulcers).

Opioids such as fentanyl and its analogs (eg, alfentanil) have higher analgesic potential and ideally are administered intravenously on demand. However, due to side effects like nausea, vomiting, and respiratory depression, they require electroencephalography and blood pressure and oxygen saturation monitoring and are less suitable in an outpatient setting.

8.5. Shock wave rate

Lower shock wave frequencies lead to better stone disintegration and produce less tissue damage. Consequently, fewer shock waves are needed, and fewer complications as well as lower retreatment rates are seen [12]. According to the EAU guidelines, the optimal shock wave frequency is 60 shock waves per minute.

8.6. Number of shock waves

Tissue damage is related not only to shock wave rate and energy but also to shock wave number. There is no consensus about the maximum number of shock waves to deliver, as it depends on various factors such as energy level, position of the stone (ureter or kidney), and type of lithotriptor [21].

8.7. Coupling

Acoustic coupling plays a critical role in successful SWL, as even small air bubbles in the gel layer between the shock wave head and the patient will reflect a remarkable amount of energy and will impair stone fragmentation.

To optimize coupling, a large amount of low-viscosity ultrasound gel should be applied directly from the stock container [51,52]. In-line ultrasound should be used to control proper acoustic coupling [18].

8.8. Abdominal compression

The use of an abdominal compression belt leads to both reduced movement of the patient and reduced respiratory movement and therefore is highly recommended. Furthermore, this compression can help reduce skin–stone distance in highly obese patients [30,53].

8.9. Power ramping

To trigger vasoconstriction, treatment should be started on a low energy level and increased stepwise. Such a protected kidney suffers less vascular damage and, consequently, less tissue damage [11,54]. In addition, better stone fragmentation and higher stone-free rates are observed [18].

8.10. Imaging during treatment

Because patients can move or stones can change position during treatment, repeat imaging is recommended to ensure optimal targeting [21]. Assessment of stone fragmentation
during treatment is difficult; indirect signs are softening of margins, loss of density, and movement of fragments [18].

8.11. Mechanical percussion, diuresis, and inversion therapy

For lower-pole stones, the combination of mechanical percussion (applied manually in prone, head-down Trendelenburg position) and forced diuresis has shown increased stone clearance [55]. Ultimately, the high effort in time and manpower seems to make this approach impractical for daily use [56].

8.12. Emergency shock wave lithotripsy

Especially for proximal ureteric stones, SWL treatment delivered in the first 6 h after the onset of renal colic has been shown to correlate with high stone-free rates [57]. An explanation for this might be the reduced ureteric peristalsis found after long-standing obstruction that makes stone clearance difficult [40].

8.13. Adjuvant drug therapy

MET following SWL results in significant increases in stone-free rates. Drugs currently in use are NSAIDs, \(\alpha\)-blockers, calcium-channel blockers, antimuscarinics, corticosteroids, terpenes, or combinations thereof. MET has to be considered “off-label” use, and the patient needs to be made aware of that and informed about potential side effects.

NSAIDs, including cyclo-oxygenase 2 inhibitors, have been shown to reduce local inflammation, edema, and ureteric contraction as well as intrarenal pressure. An improved stone expulsion rate could not be demonstrated [58,59].

For \(\alpha\)-blockers and for the calcium-channel blocker nifedipine, a higher stone-free rate, less time to stone expulsion, reduced pain, and decreased use of analgesics have been reported in the spontaneous passage of ureteric stones. Ureteric relaxation around the stone and an increase in hydrostatic pressure in the ureter above compose the proposed mechanism of action [60,61]. These benefits have been shown mainly for tamsulosin 0.4 mg (0.2 mg in the Asian population), but other \(\alpha\)-blockers are probably equally effective due to a class effect [21].

After SWL, all fragments have to pass the ureter, so it is logical to assume the same effects, and, at least for \(\alpha\)-blockers, a significant reduced time to stone expulsion, fewer colic episodes, and less need for analgesics have been reported [62].

Tamsulosin 0.4 mg (0.2 mg in the Asian population) is the best-investigated substance, but there seems to be a class effect. The use of \(\alpha\)-blockers is very convenient for urologists, who are already familiar with these drugs and their side effects. N-butylscopolamine has failed to show a decrease in the need for opioid analgesics in renal colic and did not lead to increased stone-expulsion rates [62]. Phosphodiesterase inhibitors, corticosteroids, and papaverin have a relaxing effect on ureteral muscle, have analgesic potential, and can potentially facilitate stone passage, but further studies are needed [62].

Lately, terpenes have been shown to have diuretic, anti-inflammatory, analgesic, and spasmytotical effects. They can accelerate stone expulsion and reduce symptoms in patients passing stones after SWL on renal calculi [63].

8.14. Repeat treatments

In cases of insufficient stone fragmentation, repeat SWL sessions are possible safely in the ureter even after 1 d [21]. The optimal safe period between treatments, particularly for renal stones, has not been established and remains controversial.

8.15. Follow-up after shock wave lithotripsy

There is no consensus regarding follow-up after SWL. Stone clearance needs time, and patients should be followed with adequate imaging. Because silent ureteric obstruction has been reported, assessment for hydronephrosis and outflow obstruction, preferably with ultrasound, should be performed if in doubt.

9. Pediatric shock wave lithotripsy

Due to its noninvasiveness, SWL is the first-line treatment in pediatric urolithiasis, and stone-free rates are excellent. The shorter and more elastic ureter of children clears stones better than the adult ureter. Even big calculi and staghorn stones can usually be removed with only a few treatments, and stenting is rarely required [64].

The EAU guidelines, however, recommend PCNL for pediatric stones >20 mm rather than SWL and apply the same indication criteria in children as in adults [65].

Depending on age and compliance, SWL treatment in children is usually performed under general anesthesia. Because the organs lie closer to the skin surface, less shock wave extinction is caused during travel through the tissue, and the energy level has to be adapted accordingly [64].

10. Future development in shock wave lithotripsy

Several technological advances have been developed to improve both the stone-free rate and the safety of SWL. Automated fluoroscopic localization systems and optical or acoustical tracking of the stone facilitate targeting and significantly reduce x-ray exposure [12]. Wide-focus, low-pressure lithotriptors are now commercially available; they deliver energy more effectively to the target and have a higher hit rate. The results in terms of stone fragmentation and side effects are encouraging [18].

In dual- or twin-head lithotripters, two shock wave generators are installed at a 90° angle to deliver a second shock wave to the focal point. Tandem-pulse systems have a double layer of piezoelectric, ceramic elements producing a second shock wave impulse in the same acoustic axis. These systems can be switched synchronously or with a time shift, allowing for electronic influence of multiple parameters of the shock wave and adaptation of it for different stone localizations and conditions [18].
To prevent overtreatment, acoustic feedback systems are used to monitor stone disintegration and to determine the breakage end point [18].

Clearance of residual fragments, especially in the lower pole, can be promoted by focused ultrasound that is capable of pushing stone fragments into the renal pelvis, where the chance of spontaneous clearance is maximized [18].

11. Conclusion

Nearly 30 yr after its revolutionary introduction, SWL is a well-established and safe treatment modality for the majority of stones in the UUT. Modern lithotripters are optimized to be user friendly, and treatment is only moderately painful. This advance came at the price of a lower stone-free rate and a slightly higher complication rate than with the original Dornier HM3.

Generally, in adults with normal anatomy, SWL should be the first-line treatment for non–lower-pole stones <20 mm in the kidney and for stones <10 mm in the ureter. In pediatric urolithiasis, the indications for SWL are similar to those in adults, although even staghorn stones can be treated successfully.

To maximize stone-free rate and to minimize side effects, careful patient selection, optimized treatment protocols, a well-trained operator, and supportive measures like MET are necessary.

Every urologist should be aware of the promising new technical concepts and the growing number of nonurologic applications for shock waves. Despite the progress of endourologic stone therapies, SWL will continue to play an important but slightly reduced role in urology and should be mastered by every urologist during his or her training.

Conflicts of interest

The authors have nothing to disclose.

Funding support

None.

Acknowledgment

Athanasios Papatsoris for his contribution to this review.

References


