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Complications of Shock Wave Lithotripsy*

Learning Objective: At the conclusion of this continuing medical education activity, the participant will be able to explain the complications that may occur with shock wave lithotripsy, the risk factors associated with those complications, and how to minimize the incidence of those complications.

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INTRODUCTION

Since its introduction in 1982, shock wave lithotripsy remains an attractive nephrolithiasis treatment option for patients and surgeons as it is the only completely noninvasive modality. Due to its minimally invasive nature and ease of administration, the risks of shock wave lithotripsy are often overlooked.[1] In this Update, we review the current practice patterns for shock wave lithotripsy, acute and chronic complications that may occur and maneuvers that urologists can execute to minimize the risk of complications.

PRACTICE PATTERNS

In 1998, SWL was the most commonly performed surgery for nephrolithiasis and accounted for 54% of all stone surgeries, compared to ureteroscopy, at 41%, and percutaneous nephrolithotomy, at 4%.[2] Examination of American Board of Urology recertification case logs from 2004 to 2008 revealed that URS had become the most commonly performed surgery (52%) among urologists applying for initial certification. Urologists applying for first and second recertification were still using SWL more frequently (57.4% and 60.5%, respectively). Thus, younger urologists appeared to favor endoscopic interventions over SWL.[2] **Similarly, when American Board of Urology case logs were examined from 2003 to 2012, the use of URS increased from 40.9% to 59.6%, and SWL decreased from 54% to 36.3% (fig. 1).** The shift toward URS was present among junior/senior urologists.[3] The authors speculated this shift could be due to the increased efficacy of URS as endoscopic technology has improved. Governing bodies such as the AUA and EAU also produced specific guidelines to maximize the efficacy of SWL,

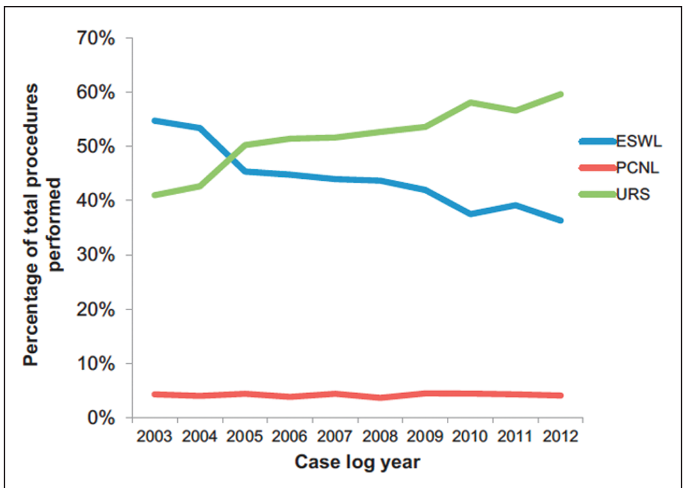

Figure 1. Change in practice patterns of extracorporeal shock wave lithotripsy (*ESWL*), URS and percutaneous nephrolithotomy (*PCNL*) over time. Reprinted with permission.[3]

which may have influenced this shift in practice patterns (see Appendix).

ACUTE COMPLICATIONS

Cardiac arrhythmias. During the initial SWL experience, cardiac arrhythmias occurred in up to 80% of patients.[4] Possible causes of cardiac arrhythmias included inadvertent mechanical or electrical stimulation of the inferior vena cava, as well as direct/indirect irritation of the atrial/ventricular myocardium. Modifications were made to synchronize early lithotripters to the patient's EKG so that the shock wave would trigger during the heart's R-wave (refractory period). **Interestingly, cardiac gating no longer seems to be required with newer lithotripters as there was no significant increase in the incidence of cardiac arrhythmias occurring in more contemporary series.[5]** In a study of 50 patients undergoing SWL with a piezoceramic generator, the authors detected atrial and/or ventricular ectopic beats in 30% of cases.[6] Nonetheless, the authors concluded that patients with an underlying history of heart disease or complex arrhythmias should be monitored with continuous EKG during the operation. Patients with cardiac pacemakers can be safely treated with SWL, but cardiac clearance should be obtained from the primary cardiologist. Recommendations for safely performing SWL in patients with pacemakers include continuous EKG monitoring, having trained pacemaker personnel on site, magnet deactivation of the device if the targeting zone is within 15 cm of the pacemaker, and immediate termination of the procedure if significant arrhythmias develop.[7]

Treatment failure. A comprehensive review of the stone-free rate of SWL and how it compares against other modalities is beyond the scope of this Update. **However, to briefly summarize, there are certain factors that will affect the success rate of SWL, including skin-to-stone distance, stone composition/Hounsfield Units, stone size, infundibulopelvic angle/stone location, length and width of infundibulum, calyceal width, altered anatomy (eg horseshoe kidney, ureteropelvic junction obstruction, calyceal diverticulum) and hydronephrosis.[8,9]** Obese patients or those with a longer skin to stone distance (>10 to 12 cm) are less likely to have successful stone comminution due to attenuation of the shock wave in adipose tissue.[9,10] Pure calcium oxalate monohydrate, brushite and cystine stones are dense, making them resistant to SWL, and are best treated via other modalities.[8] In general, dense stones (>900 HU) are less likely to fragment efficiently with SWL.[10] Patients with a single stone and lower stone volume have higher SFRs compared to those with multiple stones or higher stone volume.[8,11] Hydronephrotic kidneys and horseshoe kidneys also have a lower SFR.[8,12] Lower pole stones have a lower SFR compared to stones located in upper/middle pole and renal pelvis. Lower pole stones that are <10 mm, 11 to 20 mm and >20 mm have SFRs of 63%, 23% and 14%, respectively.[13] Hence, the AUA Guideline recommends against use of SWL for renal pelvic stones >20 mm and lower pole stones >10 mm.[14] Acute infundibulopelvic angle <90 degrees, longer infundibular length and narrow infundibulum are also associated with poorer stone clearance.[15] One group created the "Triple D scoring system" to predict the success of SWL,

ABBREVIATIONS: AUA=American Urological Association, BMI=body mass index, DM=diabetes mellitus, EAU=European Association of Urology, EKG=electrocardiogram, HTN=hypertension, SFR=stone-free rate, SWL=shock wave lithotripsy, URS=ureteroscopy assigning 1 point each for the following variables: stone density <600 HU, stone volume <150 ml and skin-to-stone distance <12 cm. Patients with 3 points had a SFR of 96% vs 21.4% for those with 0 points.[16] The urologist should consider all of these factors during patient selection to achieve the highest possible SFRs (see table).

Steinstrasse. After the stone is treated *in situ* and the fragments are allowed to pass spontaneously, patients can develop steinstrasse as multiple fragments attempt to pass through the ureter and become lodged. The incidence of steinstrasse is thought to be 2% to 10%.[17] Cases of steinstrasse may be asymptomatic and transient; thus, the incidence of steinstrasse may be as high as 15% (if routine x-rays are obtained 24 to 48 hours post-SWL).[18] In general, approximately 50% of cases of steinstrasse can be managed conservatively.[18,19] However, patients who present with acute kidney injury, infection or failure of conservative treatment (ie intractable nausea, vomiting, pain) should undergo urgent intervention (eg percutaneous nephrostomy placement, ureteral stenting, treatment consisting of URS/repeat SWL only in the absence of infection). The EAU Guideline recommends percutaneous nephrostomy placement in the setting of infection and steinstrasse.[20] Some hypothesize percutaneous nephrostomy placement facilitates spontaneous passage of fragments as decreased intrarenal pressure may increase ureteral peristalsis.[21]

Multiple studies have attempted to identify risk factors to predict who will require intervention for steinstrasse vs who can be managed conservatively. **Larger stones treated with SWL are at higher risk for developing steinstrasse as there will be more fragments to pass.[19,22]** Higher Hounsfield units, higher energy used during SWL and hydronephrosis have also been identified as risk factors for steinstrasse.[22] Denser stones may not fragment as efficiently and, similarly, higher energy is thought to result in larger, coarser stone fragments, which may obstruct more readily than finer fragments. Indeed, in one series of steinstrasse, the leading fragment being >5 mm was associated with need for intervention ($p=0.001$).[18] Hydronephrotic collecting systems may be at risk as they are hypothesized to have decreased ureteral peristaltic rates. **Routine prestenting is not recommended by the AUA (Guideline 13),[14] as it does not decrease the overall incidence of steinstrasse and will only decrease the acute presentation of steinstrasse.[19] The use of alpha blockers, such as tamsulosin, has not been shown to decrease the incidence of steinstrasse, but has been shown to improve the SFR and decrease the amount of analgesics required post-SWL, and thus they may be prescribed to facilitate passage of fragments post-SWL (AUA Guideline 40).[14,15,18]**

Table. Risk factors for SWL treatment failure

	Stone-Free Rate
Greatest stone diameter >20 mm	30%–35%[8]
Lower pole stone size >10 mm	3.3%–23.1%[13]
Skin-to-stone distance >11 mm, high BMI	59%[10]
Horseshoe kidney	29.03%[12]
Stone density >900 HU[10]	Not available
Infundibulopelvic angle <70 degrees, infundibular width <5 mm, infundibular length >3 cm[50]	Not available
≥2 stones	30%–59%[8]

Infection. **As evidenced by the AUA and EAU guidelines, which do not recommend routine antibiotic prophylaxis for SWL,[14,20] the risk of infection after SWL is low.** In a prospective cohort study, a urine dipstick and culture were obtained before and after SWL in an attempt to identify the incidence of fever, asymptomatic bacteriuria, symptomatic UTI and urosepsis.[23] A total of 389 patients were included, and antibiotics were only administered in 8 patients at the discretion of the urologist. The incidence of symptomatic UTI was 0.3% (1 case), no cases of urosepsis occurred and asymptomatic bacteriuria was detected in 2.8% of cases (11 cases). In another prospective observational cohort study with 366 patients, no antibiotic prophylaxis was used.[24] All patients submitted pre-SWL and post-SWL urine cultures. Asymptomatic bacteriuria was detected in 4.6% and symptomatic UTI in 1.2%. No cases of urosepsis occurred. In general, the rates of asymptomatic bacteriuria and urosepsis post-SWL are estimated to be 5% and 1%, respectively.[25] Multiple meta-analyses have come to the same conclusion that routine antibiotic prophylaxis is not required for patients with no risk factors undergoing SWL. **Nevertheless, in those with a history of advanced age, urinary tract abnormalities, history of recurrent UTI, recent UTI, indwelling ureteral stent/urethral catheter, percutaneous nephrostomy tube or concern for infectious stone, the urologist should consider administration of prophylactic antibiotics.[24]**

Perinephric hematoma and adjacent tissue damage. To understand the pathophysiology of how SWL can cause tissue trauma, one must have a basic understanding of shock wave physics. Briefly, for a lithotripter to comminute stone, it must have a power source (to generate the acoustic wave), a reflector element (to focus the acoustic wave), a coupling mechanism (to transmit the acoustic wave into the body) and a targeting mechanism (to visualize the stone and direct the acoustic wave).[26] The 3 types of generators currently available are electrohydraulic, electromagnetic and piezoceramic.[27] When a shock wave is generated, there is a rapid rise in positive pressure (compressive phase), which is followed by negative pressure (tensile phase).[1] Thus, acoustic waves travel as alternating phases of positive and negative pressures. Once they arrive at the stone, these waves result in direct and indirect forces that augment each other to result in stone fragmentation. These forces include spallation, circumferential compression, shear stress, cavitation and dynamic fatigue.[5,27] Cavitation occurs as microbubbles form when the negative pressure wave approaches and creates a drop in the fluid pressure. As the wave passes, the pressure rises again and the bubble collapses violently, releasing high velocity microjets that are powerful enough to pit metal in the direction of the stone![1] While these forces result in stone comminution, they can also, unfortunately, result in tissue damage. Indeed, animal studies have shown shock waves cause a vascular, hemorrhagic lesion.[28] Histological analyses from the porcine model demonstrate cortical and medullary damage to renal vasculature and tubule structures.[28,29] Inflammation and scar tissue ensue, and permanent loss of functional renal volume can result.[1,30] Cavitation bubble formation and shear stresses are thought to be the primary mechanisms of tissue damage, leading to vessel rupture, tubule damage and cell lysis.[27]

Unsurprisingly, if routine post-SWL imaging is obtained (ie computerized tomography or magnetic resonance imaging), incidental perinephric hematomas are found at a rate of ~15% to 20%.[31,32] However, symptomatic perinephric hematomas are very rare—on the order of 0.25% to 0.66%.[33] While perinephric hematomas can usually be managed conservatively, they are not always benign and can require blood transfusion. Case reports of angioembolization after segmental artery rupture[8] or even massive perinephric hematomas causing bilateral ureteral obstruction and need for temporary dialysis and ureteral stenting have been reported.[33] **If a patient presents with disproportionate flank pain and a hemoglobin drop, renal imaging should be obtained to rule out perinephric hematoma.**[8,15]

Risk factors for developing perinephric hematoma include hypertension, BMI <21.5 or >30 kg/m^2, and older age. Patients who are on antiplatelet or anticoagulation medication should hold these medications (after conferring with the primary physician prescribing the medication). The AUA White Paper on anticoagulation/antiplatelet medications recommends discontinuation of these medications prior to SWL (Statement 11) and provides guidance on when to discontinue different agents (Statements 1 to 10).[34] The EAU considers SWL a high risk procedure for bleeding and recommends discontinuation of anticoagulants such as warfarin and apixaban, aspirin (all dosages) and P2Y12 antiplatelet therapies.[20] In a retrospective review of 3,620 SWL treatments, hypertension was identified as a risk factor for perinephric hematoma. The incidence of perinephric hematoma in the overall cohort was 0.66%, but it was 2.5% in those with medically treated hypertension and 3.8% in those with poorly controlled hypertension (defined as diastolic blood pressure >90 mm Hg).[33] In a randomized, prospectively matched case control study with 418 patients, BMI <21.5 or >30 kg/m^2 was identified as a risk factor for perinephric hematoma.[32] Another prospective study identified age as a risk factor for perinephric hematoma (OR 1.67 for each 10-year incremental increase in age, 95% CI 1.13–2.45, p=0.009).[31]

Although very rare, catastrophic complications such as bowel perforation, aortic aneurysm rupture or intrahepatic hematoma requiring hepatic artery embolization have also been reported.[35,36] There have been reports of uneventful SWL in patients with aortic and renal aneurysms, but the urologist should proceed with caution or consider treatment of the aneurysm first.[35]

CHRONIC COMPLICATIONS

As explained previously, shock waves do result in tissue trauma and scarring in the kidney. Adjacent organs such as the pancreas are at risk for damage as evidenced by transient elevations in amylase and lipase, and case reports of acute pancreatitis.[8] The mechanism of how SWL might cause hypertension is unclear, but SWL does induce vasoconstriction during treatment, and transient elevations in renin and reductions in glomerular filtration rate and renal plasma flow have been demonstrated.[29,37] The transient renin elevation cannot explain long-term hypertension post-SWL, but Page kidney physiology is also theoretically possible.[33] So, although the pathophysiology is not understood, the potential for tissue trauma secondary to SWL has raised concerns about the risk of chronic complications such as new-onset HTN, DM and loss of renal function.

Hypertension and diabetes mellitus. The association between HTN, DM and SWL is controversial. One study reported 19-year follow-up data for 288 patients who underwent SWL in 1985 and found a statistically significant association between SWL and new-onset HTN and DM. Patients were matched to a cohort of nephrolithiasis patients that were treated conservatively. The incidence of HTN was 36.4% vs 27.9% at follow-up in the SWL vs control group. There was an increased risk of developing HTN after SWL (OR 1.47, 95% CI 1.03–2.10, p=0.034). The incidence of DM in the SWL vs control group was 16.8% vs 6.7%. There was an increased risk of developing DM after SWL (OR 3.23, 95% CI 1.37–6.02, p <0.001), even after controlling for BMI. Furthermore, the authors found that DM was related to the number of administered shocks and the treatment intensity (defined as kV × shock number).[38] The same group then studied the risk of SWL and HTN in a large population-based cohort study and found no association. A total of 4,782 stone formers with no baseline HTN were included with a mean followup of 6 years. No significant association between SWL and HTN was found on univariate (p=0.33) or multivariate modeling (HR 1.03, 95% CI 0.84–1.27, p=0.77).[39]

In another survey-based study exploring the risk of SWL and HTN, questionnaires were mailed to patients who underwent SWL from 1999 to 2002. SWL patients were then matched with controls obtained from the National Health and Nutrition Examination Survey database. The final cohort included 1,758 patients with a median followup of 6 years. The authors found a small but significant increase in risk of HTN after SWL (37.8% vs 32.5%, p=0.0009). Using a multivariate analysis approach, the authors then attempted to identify SWL parameters associated with HTN (eg number of shocks, bilateral vs unilateral, multiple SWL sessions) but found no association. However, male gender, family history of HTN, older age, higher BMI and abnormal blood pressure reading on day of SWL treatment were associated with developing HTN.[37] The same group used similar methods to study the risk of developing DM after SWL.[40] A total of 1,869 patients were included in the DM cohort with a median followup of 6 years. The authors were unable to find an association between SWL and DM as the incidence was 5.2% vs 5.8% (p=0.47) for the SWL vs control group.

One meta-analysis reported 24 of 30 studies showed no association between SWL and HTN, and 4 of 6 studies showed no association between SWL and DM.[41] Another meta-analysis studying the risk of HTN after SWL also found no association.[42] Part of the difficulty in identifying an association between SWL and HTN or DM is that HTN and metabolic syndrome are known risk factors for developing stones.

Two other groups recently studied the risk of HTN after SWL using the Longitudinal Insurance Research Database from Taiwan. Taiwan has a national health insurance plan that covers 98% of its population (23.7 million people) with data from 1996 to 2010.[43,44] One study compared 1,500 patients treated with SWL to 7,500 patients with nephrolithiasis who did not undergo SWL and 7,500 healthy patients without a history of stones. The incidence of HTN was 14.4%, 13.2% and 12.7% in the groups, respectively, and there was a statistically significant difference. When comparing SWL patients to stone controls, the authors found an adjusted HR of 1.24 (p=0.005), and when comparing SWL patients to healthy controls, they found an adjusted HR of 1.32 (p <0.001).[43]

Using the same database, another group used time-varying Cox models to study SWL and the risk of new-onset HTN and DM. The authors identified 9,025 patients who underwent SWL and 3,420 who underwent URS to study the risk of developing HTN. After a median followup of 74.9 and 82.6 months in the

SWL and URS groups, respectively, the incidence rates of HTN were 33.5 and 28.3 per 1,000 person-years. The authors found the SWL group had a higher probability of new-onset HTN (HR 1.20, 95% CI 1.10–1.31). Furthermore, the risk of HTN was associated with the number of SWL sessions. For example, the HR in those with a history of 1 vs ≥5 sessions was 1.10 (95% CI 1.00–1.20) vs 2.00 (95% CI 1.63–2.45). The authors also studied the risk of developing DM after SWL. There were 10,145 and 3,879 patients included in the SWL and URS groups, respectively, with median followups of 82.7 and 88 months. The respective incidence rates of DM were 13.9 and 14.5 per 1,000 person-years. No association was identified between SWL and DM (HR 0.95, 95% CI 0.85–1.06).[44]

In conclusion, most evidence suggests there is no association between SWL and DM. However, the evidence regarding the association between SWL and HTN is still conflicting. To our knowledge, there are no published meta-analyses that include the studies from Taiwan (meta-analyses only included studied published up to 2013),[41,42] and, therefore, further studies are still needed to understand the effect of SWL on HTN.

Renal function. While SWL is known to induce renal tissue trauma, measurable deterioration of renal function has not been observed. In one meta-analysis, none of the 14 included studies showed an association between chronic kidney disease and SWL.[41] In a study that utilized serial nuclear medicine ^{99m}technetium-mercapto acetyl triglycine scans, no differences in dye clearance, glomerular filtration rate or split function were detected. Nuclear medicine ^{99m}technetium-mercapto acetyl triglycine scans were performed prior to SWL and at the last follow-up (mean followup 43.6 months).[45] Similarly, using a serum creatinine-based approach, another group detected no change in glomerular filtration rate at 10-year followup.[46] **Therefore, no long-term deficits to renal function are thought to occur with SWL.**

MANEUVERS TO REDUCE RISK OF COMPLICATIONS

Patient selection. Proper patient selection is key to ensuring successful outcomes for SWL. Following the AUA Guideline, SWL should not be offered for stones >20 mm or for lower pole stones >10 mm.[14] Patients with dense stones (calcium oxalate monohydrate, brushite, cystine) or anatomy with poor urinary drainage (eg hydronephrosis, horseshoe kidney, ureteropelvic junction obstruction) will have lower SFRs.[8,9] Patients with a cardiac history or a pacemaker should be monitored carefully for cardiac arrhythmias.[7] Patients on antiplatelet/anticoagulation medication should hold these medications prior to undergoing SWL to decrease the risk of perinephric hematoma.[47] Caution is advised in patients at higher risk for perinephric hematoma (those who are older, have low or high BMI, or have hypertension).[31–33] Those with abdominal aortic or renal artery aneurysms are also at risk for aneurysmal rupture. Infection is rare after SWL, and routine antibiotic prophylaxis is not required for those with no risk factors, but prophylaxis should be considered in those at higher risk (eg history of recurrent UTI, indwelling ureteral stent or urethral catheter, percutaneous nephrostomy tube).[24]

Intraoperative strategies. In vitro and animal studies have shown that slowing the shock wave rate to <120 per minute results in improved stone fragmentation, as well as reducing renal trauma.[5] Cavitation bubbles are thought to be responsible for this effect. Microbubbles do not have time to dissipate with faster shock wave rates and actually shield the stone from subsequent shocks.[1] In one meta-analysis comparing shock wave rates of 60, 90 or 120 per minute, the authors found a statistically significant lower rate of success with a rate of 120 vs 60 or 90 per minute ($p < 0.001$ and $p=0.002$, respectively). No difference in success rate was found when comparing 60 to 90 per minute. The authors recommended a rate of 90 per minute as it did not compromise outcomes or increase complications, but had a shorter treatment time than 60 per minute.[48]

A ramping protocol has also been shown to improve stone comminution and decrease renal injury.[5,15] The protective mechanism of ramping is thought to be vasoconstrictive as the administration of dopamine, which blocks vasoconstriction, reversed the protective effect.[5] Initial studies recommended that a 3- to 4-minute pause was key to the protective effects of the ramping protocol.[49] However, as long as the kidney is allowed to acclimate to the lower power setting for 3 to 4 minutes, the ramping protocol can omit the pause.[5,15]

The first lithotripter, the Dornier HM3, required a ~950 L water bath, which acted as the coupling mechanism. The HM3 achieved high SFRs, but the lithotripter occupied too much space and also required general anesthesia. In an attempt to make the lithotripters more portable, newer lithotripters omit the water bath and use a coupling medium (eg ultrasound gel) to transmit the acoustic wave from the lithotripter's dry head into the patient.[1] Studies have shown that an 8% reduction in the coupling gel area (eg air bubbles) results in the need for 43% more shocks to maintain fragmentation.[5] **Urologists are advised to have minimal handling of the coupling medium. Ultrasound gel seems to be the best medium and should be applied in a single, large mound.[5,15,49]**

In an attempt to make SWL less painful, newer generations of lithotripters increased the surface area on which the shock waves enter the body, which decreased pain but also resulted in a narrower focal zone.[1] With a narrower focal zone, any patient movement or respiratory variation increases targeting inaccuracy (respiration can cause 5 cm renal displacement). For example, in one series the SFR was higher when patients underwent general anesthesia rather than intravenous sedation.[5] To address this issue, some newer lithotripters incorporate real-time ultrasound to deliver shock waves only when the stone is in the target zone.[5]

Regular imaging and familiarity with the aspects of your lithotripter are advised to ensure your treatment is on target. Similarly, the urologist should use regular intraoperative imaging and terminate the procedure when stone fragmentation appears complete, rather than delivering the maximum number of shocks and risk exposing the patient to unnecessary tissue trauma (severity of tissue trauma has been correlated to increasing number of shocks).[5,15,49]

Postoperative surveillance. To minimize pain after SWL, scheduled NSAIDs and alpha blockers are recommended.[15] To facilitate passage of fragments, scheduled alpha blockers are recommended, and some have even advocated the use of hydration and diuretic therapy with a 5-day course of 40 mg furosemide.[14,15,20] Percussion and inversion therapy has also been shown to be effective in increasing SFR, but it is time-intensive for the patient (fig. 2).[15] There is no consensus on what imaging should be obtained post-SWL, but in most cases an abdominal x-ray should suffice, and this is the preferred imaging modality among the urological community.[15] Lastly, for patients

Figure 2. Percussion and inversion therapy. Reprinted with permission.[7]

presenting with significant flank pain, the urologist should keep perinephric hematoma (particularly if there is a hemoglobin drop) or steinstrasse high on their differential.

CONCLUSION

SWL remains the only noninvasive surgical treatment for nephrolithiasis. It is the treatment option with the lowest morbidity, but complications can still occur. With proper patient selection, surgical technique and awareness of the potential complications, SWL can be a safe treatment tool in the urologist's armamentarium.

DID YOU KNOW?

- Patient selection is key to ensuring a successful outcome with SWL. Follow the AUA Guidelines and avoid treating non-lower pole stones >20 mm, lower pole stones >10 mm or stones in a collecting system with poor drainage/obstruction.
- No large-scale studies have demonstrated an association between shock wave lithotripsy and development of new-onset diabetes mellitus or hypertension.
- The urologist should have minimal handling of the coupling medium, use a ramping protocol, set the shock wave rate at 60 to 90 per minute, use regular intraoperative imaging to ensure there is accurate targeting and terminate the treatment when fragmentation is complete.

Appendix. American Urological Association[15] and European Association of Urology[24] guidelines and best clinical practice statements regarding SWL

Statement	**AUA**	**EAU**
Obtain urinalysis prior to intervention, with reflex culture	Yes	Yes
Patients should be advised that SWL has lower SFR than URS, but less morbidity and fewer complications	Yes	Not addressed
Recommend routine pre-stenting	No	No
Allows treatment of patients with pacemakers	Not addressed	Yes
Recommend shock wave rate of 60–90/min	Not addressed	Yes
Recommend ramping protocol for better SFR and less tissue damage	Not addressed	Yes
Ensure correct use of the coupling agent (minimal handling)	Not addressed	Yes
Use routine antibiotic prophylaxis	No	No
Use antibiotic prophylaxis if risk factors are present (indwelling stent, bacteriuria, infected stones)	Yes	Yes
Prescribe alpha blockers to facilitate passage of post-SWL fragments	Yes	Yes
Posttreatment mechanical percussion and diuretic therapy to facilitate passage of post-SWL fragments	Not addressed	Yes
SWL can be used first line for non-lower pole stone ≤20 mm	Yes	Yes
SWL can be used first line for lower pole stone ≤10 mm	Yes	Yes
SWL should not be offered first line for lower pole stones >10 mm	Yes	Yes
SWL should not be used in the patient with anatomical or functional obstruction of the collecting system or ureter distal to the stone	Yes	Yes
Maintain careful fluoroscopic/ultrasound monitoring during SWL	Not addressed	Yes
Use proper analgesia to improve SFR by reducing pain induced movement and respiratory excursion	Not addressed	Yes
If initial SWL fails, urologist should offer endoscopic therapy next	Yes	Not addressed

This Appendix is not exhaustive of all guidelines/best clinical practice statements.

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Study Questions Volume 40 Lesson 11

1. The AUA Guideline on surgical management of stones recommends SWL for the treatment of
   a. renal pelvic stones or any size calyceal stone confined to 1 calyx
   b. renal pelvic stones <25 mm or lower pole stones ≤15 mm
   c. renal pelvic stones ≤20 mm or lower pole stones ≤10 mm
   d. renal pelvic stones ≤15 mm, never for lower pole stones

2. Risk factors identified for the development of steinstrasse include
   a. larger stone burden, higher Hounsfield units and hydronephrosis
   b. larger stone burden, faster shock wave rate and obesity
   c. higher Hounsfield units, faster shock wave rate and obesity
   d. pre-stenting, hydronephrosis and higher energy settings

3. The AUA Surgical Management of Stones guideline recommends that in regard to pre-stenting and the use of alpha blockers to facilitate passage of post-SWL stone fragments
   a. pre-stenting is routinely indicated for stones >20 mm and alpha blockers are not recommended to facilitate passage of post-SWL stone fragments
   b. routine pre-stenting is not indicated, and alpha blockers may be prescribed to facilitate passage of stone fragments post-SWL
   c. routine pre-stenting is only indicated if the patient has a history of recurrent infections and alpha blockers must be routinely prescribed
   d. routine pre-stenting is not indicated, and alpha blockers should be prescribed to decrease the incidence of steinstrasse

4. The association between the development of hypertension and diabetes after SWL is
   a. strong
   b. nonexistent
   c. controversial
   d. seen after 19 years of followup

5. To achieve the best stone-free rates after SWL and minimize renal trauma intraoperatively, the urologist can
   a. set the shock wave rate at 120 per minute to complete the treatment as quickly as possible, and use minimal imaging
   b. use a ramping protocol, then set the shock wave rate at 120 per minute and deliver the planned number of maximum shocks
   c. manipulate the coupling gel to introduce air bubbles, set the shock rate at 90 per minute and deliver the planned number of maximum shocks
   d. set the shock wave rate at 60 to 90 per minute, have minimal handling of the coupling gel and use regular imaging