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SHOCK WAVE LITHOTRIPSY MONOTHERAPY FOR RENAL CALCULI

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ABSTRACT

Shock wave lithotripsy (ESWL) remains the most common treatment for renal calculi. In this article, recent literature pertaining to ESWL monotherapy of renal calculi was reviewed, with the goal of improving ESWL results through better case selection.

When selecting the optimal surgical approach for a patient, multiple factors must be considered. Factors to consider include stone-related factors (size, number, composition and location), renal anatomical factors, and patient-related factors. Each of these factors is presented in detail, with the discussion limit to non-staghorn renal calculi.

Children, the elderly, patients with hypertension, and patients with impaired renal function, may be at increased risk of ESWL complications and adverse effects and care should be taken to limit the number and energy of shock waves applied in these special cases. Absolute contraindications to ESWL remain pregnancy, distal obstruction, untreated infection, and uncorrected coagulopathy.

Key words: kidney calculi; extracorporeal shockwave lithotripsy; therapy
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INTRODUCTION

The goal of kidney stone surgical treatment is to achieve maximal stone clearance with minimal morbidity to the patient. Multiple options are currently available including extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PNL), retrograde intrarenal surgery (RIRS), and in rare cases, open or laparoscopic stone surgery. ESWL has revolutionized the treatment of kidney stone disease and the majority of “simple” renal calculi (about 80 - 85%) can be treated satisfactorily with ESWL (1-3). However, continued technical improvements in endourology, as well as the limitations of ESWL, have fueled a re-evaluation of the indications for ESWL.

When selecting the optimal surgical approach for a patient, multiple factors must be considered. Factors to consider include stone-related factors (size, number, composition and location), renal anatomical factors, and patient-related factors (Table-1). We will discuss each of these in detail with a review of the recent literature and we will limit our discussion to non-staghorn renal calculi. Absolute contraindications to ESWL remain pregnancy, distal obstruction, untreated infection, and uncorrected coagulopathy.

STONE RELATED FACTORS

Treatment Decisions by Stone Burden (Size and Number)

Stone burden remains the primary factor in deciding the appropriate treatment for a patient with kidney calculi (4) and multiple authors have attempted to provide guidelines for the appropriate selection of ESWL based on stone size and stone number. Studies of ESWL treatment of renal calculi, using a vari-

Table 1 *- Factors affecting management of renal stones.*

Stone	Renal Anatomy	Clinical (Patient)
Size	Obstruction/Stasis	Infection
Number	Hydronephrosis	Obesity
Composition	Uretero-pelvic junction obstruction (UPJO) Calyceal diverticulum Horseshoe kidney and other ectopic/fusion anomalies Lower pole anatomy	Body habitus deformity Coagulopathy Children Elderly Hypertension Renal failure

ety of lithotriptors, have reported a reduction in stone-free rates, an increase in the need for ancillary procedures and re-treatments, and an increase in the rate of residual fragments when an increasing stone burden (size and number) is treated with ESWL (5-11). Similarly, retrograde intrarenal surgery (RIRS) is also negatively affected by an increasing stone burden but to a lesser degree than ESWL. In contrast, PNL, although more invasive and often associated with higher morbidity, achieves better stone-free rates and is not affected by stone size (12).

Calculi < 10 mm in diameter are most common representing 50 - 60% of all single renal stones (10,11,13). Treatment results with ESWL for this group of patients are satisfactory and are generally independent of stone location or composition. However, as stone size increases there is a significant reduction in stone-free rates for single renal calculi treated with ESWL monotherapy with reported mean stone-free rates of 79.9% (range 63 - 90%), 64.1% (range 50 -82.7%), and 53.7% (range 33.3 - 81.4%) for stones less than 10 mm, 11 - 20 mm, and larger than 20 mm respectively (10,11,14,15). Although better results can be achieved using PNL or RIRS for stones up to 10 mm, these more invasive procedures associated with a higher morbidity rate are indicated only in special circumstances (e.g. anatomic malformation causing obstruction, ESWL failure, etc.).

Calculi between 10 – 20 mm are still largely treated with ESWL as the first line management (16). However, stone composition and location do have an impact on the results of ESWL for stones in this size range and should be carefully considered. Patients with renal stones 10 – 20 mm and factors predicting poor results with ESWL should be advised about alternative treatment modalities (PNL and RIRS).

The first-line management of renal stones between 20-30 mm remains controversial. Lingeman et al. (12) reported the frequency of multiple treatments to increase from 10% to 33% when ESWL was used to treat stones sized 1 to 2 cm and 2 to 3 cm respectively. In a later series, the stone-free rate with these larger stones was only 34% compared to 90% in the PNL-treated group (17). Similarly, Psihramis et al. (14) reported the results of ESWL for ninety-four renal stones > 2 cm with only 33% becoming stone free and patients with multiple stones having a similarly low stone-free rate of 32%. However, a wide variability in reported stone-free rates (33 - 65%) for renal calculi in the 2 – 3 cm range exists. Subsequently, ESWL, in combination with ureteral stenting, may still be considered an option if the patient is advised about the higher re-treatment rate and the lower likelihood of achieving a stone-free rate status (13).

The optimal therapy for renal stones greater than 3 cm is more definitive and ESWL should be avoided. Murray et al. (18) reported 65 treatments for renal calculi > 3 cm using ESWL monotherapy and reported an overall success rate of only 27% at 3 months. The best stone-free rate (60%) was obtained for stones < 500 mm^2 located primarily within the renal pelvis. The stone-free rate for stones with surface areas > 1000 mm^2 was a dismal 8%. Steinstrasse occurred in 23% of the patients. Likewise, Lingeman et al. (17) reported thirteen non-staghorn stones greater than 3 cm treated with ESWL monotherapy. Seventy-seven percent of the patients required further treatment, while only 29% were rendered stone free. Therefore, the procedure of choice for non-staghorn renal calculi greater than 3 cm is PNL regardless of stone size, location or composition.

In summary, for stones < 10 mm, ESWL is usually the primary approach. For stones between 10 – 20 mm, ESWL is still the first line treatment unless factors of stone composition, location, or renal anatomy shift the balance toward more invasive but definitive treatment modalities (PNL or RIRS). Stones greater than 20 mm should be primarily treated by PNL, unless specific indications for RIRS are present (i.e. bleeding diathesis, obesity, etc).

Treatment Decisions by Stone Composition

Multiple authors have reported that ESWL fragility varies between different stone compositions and even within stones of the same composition (19-23). Cystine and brushite are the most ESWL-resistant stones followed in descending order by calcium oxalate monohydrate (COM), hydroxyapatite, struvite, calcium oxalate dihydrate (COD), and uric acid (23,24). Stone composition can also affect the size of fragments produced as cystine and COM tend to produce relatively large pieces which may be difficult to clear from the collecting system (23,25). As a general rule, ESWL resistant stones (i.e. brushite, cystine, COM) should only be treated with ESWL when they are small (i.e. < 1.5 cm) with larger stones preferentially treated with PNL or retrograde intrarenal surgery (RIRS).

Cystinuric patients deserve special mention as they may undergo multiple procedures for stone removal during their lifetime (26) and this high likelihood of repeated procedures underlines the need to select the least invasive but effective treatment modality to reduce long-term morbidity. ESWL for cystine stones often yields poor results. Hockley et al. (27) reported 43 cystinuric patients treated by ESWL or PNL. Stone-free rates using ESWL for calculi 20 mm or less and more than 20 mm were 70.5% and 41% respectively, while the results for PNL were 100% and 92% respectively. Similarly, Kachel et al. (28) reported 18 patients with cystine stones and reviewed the literature and recommended ESWL monotherapy for cystine renal calculi < 15 mm and PNL for stones greater than 15 mm in diameter. The selective use of ESWL in cystinuric patients can produce acceptable results. Chow & Streem (26) performed ESWL in 31 cystinuric patients and reported an overall stone-free rate of 86.9%.

Brushite calculi are surpassed only by cystine calculi in ESWL resistance (29) and a treatment algorithm similar to cystine stones should be applied. Our published experience (30) of 30 patients with a total of 46 brushite stones reported an overall success rate for ESWL monotherapy of 65% (including fragments < 4 mm) with a mean of 1.5 ESWL sessions per stone. However, only 11% of patients became stone free. In contrast, PNL and ureteroscopy each achieved a 100% success rate with stone-free rates of 100% and 66% respectively. Of 20 kidneys with residual fragments < 4 mm, 12 had rapid regrowth to a significant size within 3 to 12 months, underscoring the importance of an aggressive metabolic work-up and medical treatment of identified stone risk factors.

The rare and very soft matrix calculi are also ESWL resistant. These radiolucent stones, often associated with urea splitting bacteriuria, are composed of as much as 65% organic matter (in comparison to 2 - 3% organic matrix in most non-infected urinary calculi). ESWL is not effective and matrix stones are best managed with PNL (31).

Stone composition in cystinuric, uric acid, and struvite stones can usually be predicted based on the patient’s clinical presentation or prior stone analyses, but the ability to differentiate pre-operatively between subgroups of calcium oxalate stones and to hopefully predict stone fragility remains elusive. Most stones are not pure in composition and the density and shape of a stone can be altered by the amount of each crystalline component.

The ability to predict stone composition from pre-operative imaging studies is potentially of great benefit in selecting the appropriate stone treatment. The use of plain x-rays to differentiate subtypes of calcium oxalate stones and the possible relationship to stone fragility was first suggested by Dretler (29,32). Wang et al. (22), using x-ray patterns to predict stone fragility, found that smooth edged stones with a homogenous structure needed significantly more shock waves to be completely fragmented compared to rounded, radially reticulated stones with spiculated edges, or stones with an irregular margin and structure. Likewise, Bon et al. (33) found that smooth, uniform, bulging stones which appeared denser than bone (12th rib or transverse process) responded poorly to ESWL; the stone-free rate for smooth radiologically dense and for stones with an irregular outline was 34% and 79% respectively. Unfortunately, in a recent prospective study, the overall accuracy of predicting stone composition from plain radiographs was reported to be only 39% and insufficient for clinical use (34).

The emergence of non-contrast computed tomography (NCCT) in the assessment of renal colic has led to a growing interest in comparing NCCT attenuation values with stone composition. Mostafavi et al. (35), in an in vitro study using spiral CT absolute attenuation values at 2 energy levels, was able to accurately predict the chemical composition of pure urinary calculi. Likewise, Saw et al. (36) in an in vitro study, found that CT scanning at 1 mm collimation (120 kV) was able to differentiate between stone groups (each containing at least 60% of one stone constituent) based on absolute attenuation values. The authors reported a definite effect of stone size on attenuation measurements and a dramatic effect of beam collimation width on the measured attenuation (36). Finally, CT attenuation values in vitro may even predict the fragility of calcium stones (37).

TREATMENT DECISIONS BY RENAL ANATOMY

Congenital or acquired anatomical factors that impair renal drainage are known risk factors for both kidney stone disease and impaired stone clearance with ESWL. Congenital anomalies associated with a higher risk for kidney calculi include ureteropelvic junction obstruction (UPJO) (38), horseshoe kidney and other ectopic or fusion anomalies (39), and calyceal diverticula (40). Additional anatomical factors lowering the success of ESWL stone clearance include hydronephrosis (41,42), distal obstruction (5) and lower pole calyceal location.

Ureteropelvic Junction Obstruction

Ureteropelvic junction obstruction (UPJO) in adults is commonly associated with urinary stones. However, distinguishing between primary UPJO and obstruction due to edema from an impacted UPJ stone can be difficult. Furthermore, the presence of a stone at the UPJ may worsen the degree of pre-existing obstruction and potentially exacerbate an already compromised renal unit (25). Stasis of urine has been the presumed etiology of stone formation in these patients, but Husmann et al. (43) reported a high incidence of metabolic abnormalities in this population. The authors reviewed the records of 111 patients with simultaneous UPJO and renal calculi and found that 71% of patients with non-struvite stones were found to have significant metabolic abnormalities. Furthermore, greater than 60% of recurrent calculi in the non-struvite group occurred in the contralateral kidney. Likewise, of 22 pediatric patients treated for UPJO associated with renal calculi at a median follow-up of 9 years, 68% had recurrent stones (38).

Calyceal Diverticula

The incidence of stone formation in calyceal diverticula ranges from 9.5 to 39% (44-46). Most diverticula do not require intervention, as only one third of patients become symptomatic. Stasis of urine in the diverticulum is believed to be the underlying cause of the stone formation. Although Hsu & Streem (47) reported metabolic abnormalities in 50% of 14 patients with calyceal diverticular calculi, Bell & Lingeman (48) reported long-term follow-up of 44 patients with calyceal diverticular calculi treated with PNL (mean follow-up 47 months) and found that stone recurrence occurred in only 13% of patients. Likewise, Liatsikos et al. (49) found a low incidence of metabolic abnormalities in 49 patients with calyceal diverticular stones.

ESWL monotherapy for diverticular stones remains controversial and is appropriate only in a few selected cases (40,50). Streem & Yost (51) reported 19 patients with diverticular stones < 1.5 cm and a functionally patent diverticular neck. Stone-free and symptom-free rates at a mean follow up of 24 months were 58% and 86% respectively. Although the stone free rate for calyceal diverticular stones treated with ESWL averages only 21% (range 4 - 58%), an average of 60% (range 36 - 86%) may be rendered symptom free (at least temporarily) following ESWL (13). However, to prevent stone recurrence, eradication of the diverticulum must accompany stone removal, and PNL remains the treatment of choice (40).

Horseshoe Kidney and Renal Ectopia

Horseshoe kidney is the most common congenital fusion anomaly and up to two-thirds of patients with horseshoe kidneys experience urinary stasis/hydronephrosis, infection, or urolithiasis (52,53). A common finding is the high insertion of the ureter into an elongated anteriorly rotated renal pelvis resulting in impaired urinary drainage. The results of ESWL for horseshoe kidney stones vary widely and stone-free rates between 28% and 78% have been reported (53-58). When stratified by location, Theiss et al (55) reported poorer results with lower calyceal stones compared to mid and upper calyceal stones (stone free rate of 100% vs. 53.8%). Stone size is also a factor in stone clearance from a horseshoe kidney. Kirakali et al. (56) reported a stone free rate of 28% in 18 patients with stones greater than 11 mm in diameter.

In addition to poor results with ESWL, a high rate of stone recurrence in patients with retained fragments is reported. Lampel et al. (56) reported a recurrence rate of 86% (6 of 7 kidneys) in patients with retained fragments in comparison to a 14% recurrence rate in patients who were stone free.

Renal calculi in horseshoe kidneys treated with ESWL require a higher number of shock waves per treatment and have a higher re-treatment rate (30% vs. 10%) than similar stones in normally located renal units (5,6,59). The anomalous orientation of the calyces also makes localization of the stone during ESWL more difficult, especially for stones lying in the antero-medial calyces. Prone positioning can often assist in stone localization (60) or the “blast path” technique can be utilized (61).

In summary, ESWL in cases of horseshoe kidney can achieve satisfactory results in properly selected patients with small stones (< 1.5 cm) and normal urinary drainage. For larger stones or in cases of impaired urinary drainage, PNL should be used as the primary approach.

An ectopic kidney can be found in a pelvic, iliac, abdominal, thoracic, or crossed position. The pelvic kidney is most common with an estimated incidence of 1 in 2200 to 1 in 3000 in autopsy series (62). Although the retroperitoneal location of the kidney in the pelvis may create positioning problems during ESWL, calculi in pelvic kidneys should be approached initially with ESWL whenever feasible (63,64). If the stone is shielded from the shock wave by the bony pelvis, prone positioning may be utilized. When ESWL fails or when a large stone burden is present, alternative modalities should be used. Kupeli et al. (54) reported 7 patients with pelvic kidney calculi treated with ESWL with successful fragmentation in most patients. However, the stone free rate at three months was only 54%.

Lower Pole Stones (LPS)

Multiple authors utilizing a variety of lithotriptors have documented impaired stone fragment clearance from the lower pole calyx following ESWL (14,15,65,66). An increase in the percentage of ESWL treatments for renal calculi in the lower pole has also been reported (2% in 1984 to 48% in 1991) (15). Lingeman et al. (15) reported the results of a meta-analysis which showed that the overall stone-free rate for ESWL when applied to LPS was 60%. In comparison, the results of ESWL for upper and middle calyceal stones range from 70 - 90% (13). Furthermore, stone size affects the results of ESWL treatment for LPS more than it does the results for stones in other calyceal locations. When stratified by stone size, the results of the meta-analysis showed a stone-free rate of 74%, 56%, and 33% for stones < 10 mm, 11 – 20 mm, and > 20 mm respectively (15). Havel et al. (67), in a retrospective study comparing the efficacy of ESWL (587 patients) and PNL (73 patients) for LPS, found no significant difference between the two treatment modalities for stones less than 10 mm (stone-free rate 84% and 69% for PNL and ESWL respectively). However, PNL was superior to ESWL in the treatment of stones 10 –20 mm in diameter (72.5% vs. 44%). As expected, PNL had a higher morbidity rate than ESWL (7% vs. 0.5% for LPS < 10 mm and 20% vs. 15% for LPS < 10 – 20 mm). The authors concluded that although PNL is superior to ESWL in the treatment of midsize LPS (10 – 20 mm), the higher morbidity associated with PNL may favor the use of ESWL as the initial approach, accepting the high likelihood of repeat ESWL sessions. Likewise, May & Chandhoke (68) used a decision analysis model to determine the cost-effectiveness of ESWL and PNL for lower pole stones. In the model design, if the primary treatment (either ESWL or PNL) failed, the patient underwent PNL as a salvage therapy. The authors suggested that treatment of LPS < 20 mm is more cost effective with ESWL as the initial approach, while stones > 20 mm are treated more cost-effectively using primary PNL. In contrast, a cost analysis by Riddell et al. (69) reported that while PNL and ESWL were equally effective for stones less than 10 mm, PNL was more cost-effective for larger stones. Similarly, the results of the Lower Pole Study Group (70) suggest that PNL should be considered as the primary approach for LPS > 10 mm.

Clearance of stone fragments from the lower pole following ESWL may be influenced by lower pole collecting system anatomy. Sampaio first described the spatial anatomy of the lower pole as a possible factor in stone passage (71,72). Using endocasts from cadaveric kidneys to study the anatomy of the renal collecting system, 3 anatomical features that potentially affect stone clearance were described: the angle between the lower pole infundibulum and the renal pelvis, the diameter of the lower pole infundibulum, and the spatial distribution of the calyces. The authors measured the lower pole infundibulopelvic angle (LIP) as the angle created by the lower border of the pelvis with the medial border of the lower pole infundibulum. They suggested that a LIP less than 90 degrees, lower pole infundibulum diameter less than 4 mm, and multiple lower pole calyces may decrease stone clearance (73). In a later prospective trial, Sampaio et al. (74) found that 39 of 52 (72%) patients became stone free when the LIP angle was > 90 while only 5 of 22 (23%) patients were stone free when the angle was < 90. Using the parameters described by Sampaio, Sabnis et al. (75) reported that patients with favorable factors had a post ESWL clearance rate of 70% or greater, whereas those with unfavorable factors had a clearance rate of less than 20%. Using the same method of measuring the LIP angle as Sampaio and Sabnis, Keeley et al. (76) reported 116 patients that underwent ESWL for LPS. The LIP angle was the only factor to attain significance in predicting stone-free status. The stone-free rate was 34% and 66% in patients with LIP angle of less than 100 degrees or more than 100 degrees respectively. Combining all 3 negative factors (i.e. an acute angle, distorted calyx, and narrow infundibulum), the stone-free rate dropped to 9%. With 3 positive factors, the stone-free rate was 71% (76). Elbahnasy et al. (77) in a retrospective study of 159 patients reviewed the impact of radiographic spatial anatomy on the results of ESWL, PNL, and RIRS. The authors measured the LIP angle on the preoperative IVP as the angle between two lines; the ureteropelvic axis (a line drawn through the central point of the renal pelvis and central point of the proximal ureter) and the central axis of the lower pole infundibulum. The authors reported that the LIP angle and the infundibular width (IW) played a significant role in stone clearance after ESWL for LPS, and added infundibular length (IL) as an additional significant predictive factor. All patients with three favorable factors i.e., LIP > 70°, IL < 3 cm, and IW > 5 mm, became stone free. Conversely, in patients with a combination of 3 unfavorable factors (5% of all patients) (i.e., LIP 40°, IL > 3 cm, and IW 5 mm), only 16% became stone free (77). Similarly, Gupta et al. (78) reported recently the results of 88 patients undergoing ESWL for LPS. The LIP angle was reported as the most significant factor affecting LPS clearance followed by infundibular width IW. However, infundibular length was not a statistically significant factor for stone clearance. In contrast, the results from a recent small prospective randomized study failed to show an effect of differences in parameters of intra-renal anatomy on stone clearance following ESWL (70).

In summary, ESWL is the preferred initial approach for most patients with LPS < 1 cm, while PNL is the front-line therapy for stones greater than 2 cm. For patients with stones between 1 and 2 cm, stone composition and lower pole spatial anatomy should be considered when choosing a treatment approach.

TREATMENT DECISIONS BY PATIENT-RELATED FACTORS

Any co-existing clinical factors that may impact on the treatment results and safety of ESWL must be considered pre-operatively. Urinary tract infection in the presence of stones can be difficult to eradicate unless the stones are completely removed. In these patients, PNL or ureteroscopy may be preferable to ESWL. Although the incidence of sepsis following ESWL is less than 1%, the risk of sepsis increases if the urine culture is positive and in the presence of obstruction (79,80). ESWL should be performed only if the urine is sterile and there is no distal obstruction. In general, prophylactic antibiotics are not required before ESWL but should be considered in high-risk patients (81-83).

Morbid obesity poses a problem to the successful treatment of kidney stones. The ESWL gantry or table may not be able to support the weight of the patient and the increased distance from the skin surface to the stone may render positioning of the stone at the focus of the shock wave impossible. Utilization of the "blast path" may be necessary to overcome this problem (84). Although successful ESWL treatment in obese patients (weight range 300 - 402 pounds) was reported with an overall stone free rate at 3 months of 68% (85), higher energy settings are required. When a choice is available between different ESWL machines, the patient should be placed on a machine with a greater focal length and higher peak pressures (86).

Although ESWL in patients with uncorrected coagulopathy can result in life-threatening hemorrhage, such patients can be treated once the bleeding diathesis is corrected (87). However, when anticoagulation cannot be temporarily discontinued, the use of ureteroscopy in combination with Holmium: YAG laser lithotripsy is preferred. Grasso et al. (88) reported that even when patients' coagulopathies were not fully corrected, stones could be successfully treated with no increase in complications from bleeding.

Children, the elderly, patients with hypertension, and patients with impaired renal function, may be at increased risk of ESWL complications and adverse effects and care should be taken to limit the number and energy of shock waves applied in these special cases (89-91).

CONCLUSION

ESWL remains the predominant therapy for renal calculi. Proper patient selection with therapy based on a comprehensive evaluation of stone related factors (size, number, location, composition), renal anatomy, and patient clinical factors will allow the patient to be treated with the most efficient method of achieving a stone free status with low morbidity.

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