Renal Stone Features Are More Important Than Renal Anatomy to Predict Shock Wave Lithotripsy Outcomes: Results from a Prospective Study with CT Follow-Up

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Abstract

Introduction: Lower pole kidney stones have been associated with poor shock wave lithotripsy (SWL) outcomes because of its location. However, the real impact of collecting system anatomy on stone clearance after SWL is uncertain. There is a lack of prospective well-controlled studies to determine whether lower pole kidney stones have inferior outcomes than nonlower pole kidney stones when treated with SWL.

Methods: We prospectively evaluated patients with a single kidney stone of 5–15 mm undergoing SWL from June 12 through January 19. All patients were subjected to computed tomography before and 3 months after the procedure. Demographic data (age, gender, and body mass index), stone features (stone size, stone area, stone density, and stone–skin distance—SSD), and collecting system anatomy (infundibular length and width, and infundibulopelvic angle) were recorded. Outcomes (fragmentation and stone clearance rates) were compared between lower pole and nonlower pole cases. Then, a multivariate analysis including all variables was performed to determinate which parameters significantly impact on SWL outcomes.

Results: One hundred and twenty patients were included in the study. Mean stone size was 8.3 mm and mean stone density was 805 Hounsfield units. Overall stone fragmentation, success, and stone-free rates were 84.1%, 64.1%, and 34.1%, respectively. There were no significant differences in stone fragmentation (76.0% vs 71.4%; $p=0.624$), success rate (57.6% vs 53.3%; $p=0.435$), and stone-free rate (40.2% vs 35.7%; $p=0.422$) in the lower vs nonlower pole groups, respectively. On multivariate analysis, only stone density ($p<0.001$) and SSD ($p=0.006$) significantly influenced fragmentation. Stone size ($p=0.029$), stone density ($p=0.002$), and SSD ($p=0.049$) significantly influenced kidney stone clearance.

Conclusions: Stone size, stone density, and SSD impact on SWL outcomes. Lower pole kidney stones have similar fragmentation and stone clearance compared with nonlower pole kidney stones.

Keywords: anatomy, computed tomography, kidney, lithotripsy, urinary calculi

Introduction

ALTHOUGH ENDOUROLOGIC PROCEDURES, such as retrograde intrarenal surgery and minipercutaneous nephrolithotomy (mPCNL), have gained popularity for renal stone management >2.0 cm, shock wave lithotripsy (SWL) remains as first-line treatment option for these cases.^{1,2} SWL is an option for kidney stones <20 mm, although poor outcomes have been described for large (10–20 mm) lower pole stones. If favorable parameters (stone size, stone density, and stone–skin distance—SSD) are presented, SWL can be offered for treatment of lower pole kidney stones.

As stone size is an important risk factor for SWL failure, we limited our study to <15 mm stones. It has low morbidity and reasonable stone-free rates when applied to the right patient.^{3,4} As such, there is disagreement between the EAU and AUA guideline recommendations for the upper limit of size for consideration of SWL as a management option for lower pole stones (15 vs 10 mm, respectively).

When choosing SWL, several factors should be taken into account to optimize outcomes. Stone size, stone density, and SSD may impact on SWL outcomes.^{5,6} Renal collecting

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system anatomy has also been implicated on SWL stone-free rate, especially when treating lower pole stones.^{7–9} Infundibular length, infundibular width, and infundibulopelvic angle have already been suggested as important variables on kidney stone clearance; however, no consensus has been achieved.

Most of studies evaluating SWL outcomes were published with ultrasonography (US) plus KUB for postoperative assessment of outcomes.¹⁰ It is an important limitation, as small residual fragments or stones with low density can be missed. Computed tomography scan (CT) is the gold standard examination for renal stone evaluation, providing a higher accuracy for assessing post-SWL outcomes.^{11,12} Postoperative CT scan imaging is important in the research setting to provide more reliable data regarding stone fragmentation and stone clearance, thereby establishing a higher level of quality evidence of SWL outcomes.

In this study, we aimed to perform a prospective well-controlled evaluation of all variables that may impact on renal stone clearance, including kidney stone features, patient's body habitus, and collecting system renal anatomy. We hypothesized that lower pole stones have similar outcomes to nonlower pole stones when treated with SWL.

Patients and Methods

Study design

After institution's ethics committee approval, a detailed written informed consent was obtained from each subject. We prospectively evaluated patients with a single kidney stone undergoing SWL from June 2012 through January 2019. Patients were included in the study if they had a single symptomatic stone of 5–15 mm located in the lower pole (June 2012 to August 2014) or in the central region or upper pole (July 2017 to January 2019). First, the study was designed to evaluate the impact of renal anatomy on SWL for lower pole kidney stones⁹ and then patients with nonlower kidney pole were included in the protocol. From 2012 to 2019, there was no change in our lithotripter equipment or treatment protocol (detailed in the *SWL technique* section). PCNL in our institution is offered for patients with kidney stone burden >20 mm located in the central region and upper pole and >15 mm in the lower pole, thus no patient in this study was candidate for PCNL. Flexible ureteroscopy is reserved for patients with multiples stones, SWL failure, or residual fragments after PCNL (stone burden <20 mm), because of the higher costs of performing flexible ureteroscopy and the higher invasiveness of the procedure. Single symptomatic kidney stone <15 mm is primarily treated with SWL.

Exclusion criteria were patients <18 years old, patients with multiple ipsilateral calculi, patients with congenital kidney abnormalities (i.e., horseshoes kidney, pelvic kidney, and ectopic kidney), patients with ureteral stent (i.e., Double J stent) in the ipsilateral kidney of the stone in the study, patients with chronic kidney disease (glomerular filtration rate <60 mL/minute per 1.73 m² measured by the equation "Modification of Diet in Renal Disease"),¹³ and patients with absolute contraindication to SWL (i.e., coagulopathy, pregnancy, urinary tract infection, or abdominal aneurysm >4.0 cm).

All patients had their demographic data recorded including age, gender, and body mass index (BMI). Following our institutional protocol, all patients were subjected to an anes-

thesia preoperative evaluation before SWL, including serum examinations and urine culture.

Before SWL, all patients underwent a noncontrast computed scan—NCCT (Philips CT Brilliance 64-channel; Philips, Stamford, CT) to assess stone size, stone area, stone density, SSD, and anatomic features of the renal collecting system. The images were obtained using a high-quality mode at 200–300 mA, based on patient's corporal habitus, 120 kV, and 1.00 mm collimation. All variables were assessed after a magnification of the area in the study. In the CT bone window, stone size was measured by the largest diameter of the calculus, and stone area was calculated using an advanced workstation (ADW; General Electric, Milwaukee, WI). Mean stone attenuation (Hounsfield Units—HU) of three consecutive measurements using a region of interest of 0.005 cm² was used in the study. The SSD was calculated by measuring three distances from stone to the skin at 0, 45°, and 90°; then the average of these values was established as SSD for each stone.⁵ Anatomic parameters were measured on coronal view as follows: infundibular length—the distance between the most distal point of the calix containing the calculus and the renal pelvis; infundibular width—the narrowest point on the axis of the infundibulum; infundibulopelvic angle—the angle between the line drawn through the central axis of the infundibulum/calix and the ureteropelvic axis.⁸

After 1 week of SWL, all patients were evaluated to assess symptoms and complications (i.e., pain, macroscopic hematuria, urinary tract infection, and steinstrasse). Patients with significant pain were subjected to imaging examinations (initially, US and X-ray, and then NCCT if prior examinations were inconclusive) in the emerging department. After 3 months, all patients underwent a new NCCT scan using the same parameters to evaluate stone fragmentation and stone clearance. Stone free was defined as the absence of residual fragments and success was defined as the presence of fragments <4 mm in asymptomatic patients.

SWL technique

SWL was performed using an electromagnetic lithotripter Compact Delta (Dornier MedTech GmbH, Wessling, Germany). All procedures were done under general anesthesia; antibiotic prophylaxis was not routinely performed. The stones were localized by fluoroscopy or US, if the stones were radiolucent. A total of 3000 shocks were delivered, using a rate of 90 shocks per minute. We established 90 Hz in our institution as the best option for SWL after reviewing literature about this subject and performing our own study comparing 90 and 60 Hz.¹⁴ Energy of shocks was gradually increased until it reached the higher potency of the device (18 kV). After the procedure, the patients stayed in hospital for 2–4 hours in a recovery room under medical supervision. Patients were discharged from hospital with oral analgesics to be taken in case of pain and alpha-blockers (doxazosin 4 mg/day) to be taken daily for 30 days.

We have two specialized nurses in our institution with >10 years experience with SWL. They were responsible for helping with localization (US and fluoroscopy) for all SWL.

Statistical analysis

Sample size was calculated assuming that lower pole kidney stones would have a stone-free rate of 35%, whereas

nonlower pole kidney stones would present a better outcome ~70%. These numbers were based on prior significant reports of stone-free rate after SWL.^{5,9,15} Considering a power of 80% for the study and an alpha-value of 0.05, the calculated sample size was 27 cases for each group.

Basic descriptive data were expressed in proportion, mean, and standard deviation. Univariate (Student's *t* test) and multivariate analyses (binary logistic regression) were done to assess the impact of BMI, patient's stone characteristics (size, area, density, and SSD), and renal collecting system anatomy (infundibular length and width, and infundibulopelvic angle) on SWL outcomes. Variables included in the multivariate analysis were BMI, stone size, area and density, SSD, and all anatomic measurements. SWL outcomes in the lower pole stones were also compared with those in the nonlower pole stones. All statistical analyses were performed using SPSS version 20.0 (SPSS, Inc., Chicago, IL). Significance was set at two-tail *p*-value <0.05.

Results

SWL was indicated for 125 patients with single renal stones; however, 2 patients elected not to undergo SWL and 3 patients refused the follow-up NCCT and were then removed from the study. One hundred and twenty patients fulfilled the inclusion and exclusion criteria and were enrolled in this study. There were 92 patients with lower pole stones and 28 patients with nonlower pole stones. Mean age and BMI were 47.6 years and 27.6 kg/m², respectively. Mean stone size was 8.3 mm and mean stone density was 805 HU. Table 1 summarizes the demographic data, stone characteristics, and renal collecting system anatomy features. We had 15% (18 of 120 cases) of patients with radiolucent stones. The small number of cases prevents us a subanalysis comparison between the groups.

Overall stone fragmentation, success, and stone-free rates were 84.1%, 64.1%, and 34.1%, respectively. After SWL, 38.3% of patients had lumbar pain and 37.5% had macroscopic hematuria for >48 hours. All of them were clinically

TABLE 1. DEMOGRAPHIC DATA, STONE CHARACTERISTICS, AND RENAL COLLECTING SYSTEM ANATOMICAL MEASUREMENTS

	Mean ± Standard Deviation	Minimum	Maximum
Patients (N = 120)			
Age (years)	47.6 ± 12.7	18	72
Weight (kg)	73.2 ± 13.1	44	102
Height (m)	1.62 ± 0.1	1.42	1.97
BMI (kg/m ²)	27.6 ± 4.6	18.3	40.3
Stones			
Size (mm)	8.3 ± 2.3	5	14
Area (mm ²)	27.4 ± 18.1	5	100
Density (HU)	805.3 ± 337.0	240	1,700
SSD (cm)	9.0 ± 1.7	5.3	13.7
Renal collecting system anatomy			
Infundibular length (mm)	26.5 ± 6.4	12.7	61.7
Infundibular width (mm)	5.9 ± 2.5	1.7	17
Infundibulopelvic angle (°)	74.7 ± 37.4	34.8	176

BMI = body mass index; HU = Hounsfield unit; SSD = stone-skin distance.

TABLE 2. COMPARISON BETWEEN THE LOWER POLE AND NONLOWER POLE KIDNEY STONE GROUPS FOR DEMOGRAPHIC DATA, STONE PARAMETERS, AND ANATOMIC FEATURES

	Lower pole (n = 92)	Nonlower pole (n = 28)	p-value
Age (years)	46.4 ± 12.0	50.9 ± 14.3	0.134
Weight (kg)	74.0 ± 13.2	70.5 ± 12.5	0.199
Height (m)	1.63 ± 0.1	1.63 ± 0.09	0.997
BMI (kg/m ²)	27.9 ± 4.8	26.5 ± 4.1	0.131
Stones			
Size (mm)	8.4 ± 2.2	7.9 ± 2.7	0.355
Area (mm ²)	28.3 ± 17.3	24.5 ± 21.9	0.404
Density (HU)	783.8 ± 308.1	875.9 ± 416.9	0.286
SSD (cm)	9.3 ± 1.8	8.7 ± 1.4	0.211
Renal collecting system anatomy			
Infundibular length (mm)	25.4 ± 6.1	29.9 ± 9.8	0.03
Infundibular width (mm)	6.4 ± 2.5	4.3 ± 1.6	<0.001
Infundibulopelvic angle (°)	56.7 ± 14.3	133.7 ± 28.3	<0.001

managed with oral analgesics (first nonsteroidal and then morphine if pain persists) and hydration. Only 5 (4.1%) patients presented to the emergency department because of lumbar pain. These patients were subjected to imaging examinations and two (1.6%) were diagnosed with ureteral stones. Complications requiring medical intervention were seen in 5% of patients (3.4% had urinary tract infection that was effectively treated with oral antibiotics—Clavien 2%—1.6% had steinstrasse that required ureteroscopic lithotripsy and Double J placement—Clavien 3).

On univariate analysis comparing patients with lower pole and nonlower pole stones, there were no differences regarding age (46.4 vs 50.9 years; *p* = 0.134) and BMI (27.9 vs 26.5 kg/m²; *p* = 0.131). There were also no significant differences in the stone size, stone area, stone density, and SSD. When comparing stone location, as expected there were significant differences between the groups, especially in the infundibulopelvic angle (56.7° in the lower pole group vs 133.7° in the nonlower pole group; *p* < 0.001). Table 2 gives the comparison between the groups for demographic data, stone parameters, and anatomic features. Although there were differences in the renal collecting system, SWL outcomes were not significantly different between the groups. Stone fragmentation was 76.0% vs 71.4% (*p* = 0.624), success rate was 57.6% vs 53.3% (*p* = 0.435), and stone-free rate was 40.2% vs 35.7% (*p* = 0.422) in the lower pole vs nonlower pole kidney stones groups, respectively. Table 3 summarizes these data.

TABLE 3. COMPARISON BETWEEN THE LOWER POLE AND NONLOWER POLE KIDNEY STONE GROUPS FOR SHOCK WAVE LITHOTRIPSY OUTCOMES

	Lower pole (n = 92)	Nonlower pole (n = 28)	p-value
Fragmentation (%)	76.08	71.42	0.624
Success (%)	57.61	53.57	0.435
Stone free (%)	40.21	35.71	0.422

On multivariate analysis searching for variables that could impact on SWL outcomes, only stone density ($p < 0.001$) and SSD ($p = 0.006$) significantly influence on fragmentation, whereas only stone size ($p = 0.029$), stone density ($p = 0.002$), and SSD ($p = 0.049$) influence on kidney stone clearance. There was no anatomic parameter significantly impacting on SWL outcome.

Discussion

SWL has been indicated for decades in the treatment of kidney stones; however, with the increasing technology and miniaturization of endoscopes and devices, its role has been diminishing, particularly among younger urologists.^{16,17} The large range of success rates reported may make urologists and patients uncertain about its real efficacy.^{18,19} When treating lower pole kidney stones, there is always the concern whether stone clearance after SWL will be negatively affected by the collecting system anatomy. In this study, we looked at variables that could impact on SWL outcomes and demonstrated that stone features are more important than collecting system anatomy in anatomically normal kidneys.

The concept that lower pole kidney stones experience poor outcomes when treated with SWL is not new and has been the focus of several studies.^{5,7-9} Sampaio et al. were the first to study and propose a narrow infundibulopelvic angle, an infundibular width < 4 mm, and the presence of multiple calices in the lower pole as negative factors for SWL.⁷ Elbahnasy and colleagues added the infundibular length to the renal collecting system evaluation and proposed an infundibulopelvic angle $< 70^\circ$, an infundibular length > 30 mm, and an infundibular width ≤ 5 mm as negative factors for SWL.²⁰ We have previously reported that the worst outcomes of SWL in the lower pole kidney stones are achieved in obese patients with stones > 10 mm, stone density > 900 HU, and infundibular length > 25 mm. Of four positive variables correlated with poor outcomes, three were not linked to the collecting system anatomy.⁹ Thus, we decided to study together the impact of BMI, stone features, and anatomic parameters on SWL for all stones to find out what is really important when indicating SWL. In this article, we found similar outcomes (fragmentation rate and clearance rate—success or stone free) for lower pole and nonlower pole kidney stones. Moreover, in the multivariate analysis, only stone size, stone density, and SSD impacted on stone clearance. When evaluating kidney stones in all locations, probably infundibular length becomes less important because of its low impact on central region and upper pole stones. Maybe it is variable particularly important in few cases of lower pole kidney stones.

Prior studies have described inferior outcomes of SWL for the lower pole kidney stones when compared with stones located in the central region or upper pole.^{7,8,21-24} However, these studies were retrospective in design and utilized KUB plus US to assess postoperative outcomes.

El-Nahas et al. in a prospective and well-controlled study using CT scan reported that SWL outcomes are correlated with stone density (> 1000 HU) and obesity (BMI > 30 kg/m²).⁵ Wiesenthal and colleagues in a retrospective study of 422 patients reported after a multivariate analysis that stone density < 900 HU and SSD < 11 cm were significantly associated with favorable outcomes.⁶ Although in our study BMI was not significantly linked to worse outcomes,

high stone density and large SSD were associated with poor stone clearance. We speculate that SSD better reflects the impact of corporeal habitus of the patients on SWL than BMI. Stone size was another variable that impacted on SWL outcomes. Other authors have already proved that and it appears to be a consensus in the literature.^{25,26}

In our study we have success and stone-free rates of 64.1% and 34.1%, respectively. Recent studies that have used CT scan to evaluate the SWL outcomes reported similar outcomes.^{15,27,28} Also, our complication rate is in accordance with prior publications.^{18,29,30}

Our study has limitations. First, renal collecting system anatomy was evaluated by CT scan without contrast, which is not the gold standard examination for this purpose. However, there are studies showing its feasibility and equivalence to intravenous urography.³¹ Second, sample size in the nonlower pole group was considerably smaller, but it was enough based on our sample size calculation. Lastly, our groups were not evaluated in the same period, as the lower pole group was analyzed few years earlier and then the nonlower pole group was incorporated to the study.

Conclusion

Stone size, stone density, and SSD impact on SWL outcomes. Lower pole kidney stones have similar fragmentation and stone clearance compared with nonlower pole kidney stones. Stone location alone should not discourage urologists for SWL indication.

Author Disclosure Statement

No competing financial interests exist.

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Abbreviations Used

BMI = body mass index
 CT = computed tomography
 HU = Hounsfield unit
 mPCNL = minipercutaneous nephrolithotomy
 NCCT = noncontrast computed scan
 PCNL = percutaneous nephrolithotomy
 SSD = stone-skin distance
 SWL = shock wave lithotripsy