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The Effects of Hydronephrosis and Stone Burden on Success Rates of Shockwave Lithotripsy in Pediatric Population

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Abstract

Objectives: To evaluate the efficacy of shockwave lithotripsy (SWL) with a third-generation SWL machine in the pediatric age group and to determine the effects of stone burden and the degree of hydronephrosis on the results.

Methods: Two hundred and sixty children with urinary system stones were treated with Siemens Lithostar Modularis Uro-Plus. The patients were divided into three groups according to stone burden (group 1: $<100\,mm^2$; group 2: $101–200\,mm^2$; group 3: $>200\,mm^2$) and into four groups according to the degree of hydronephrosis (group 0: absent; group 1: mild; group 2: moderate; group 3: severe). These groups were compared in terms of the success rate of SWL.

Results: Two hundred and seventy-nine renoureteral units of 260 patients were treated with 402 SWL sessions. The average stone burden was $98.2\,mm^2$ (range: 11–525). The overall success rate was 87.5%. According to stone burden, the success rate was 93.1% in group 1, 85.5% in group 2, and 60% in group 3 ($p < 0.001$). According to the degree of hydronephrosis, the success rate was 93.8% in group 0, 89.6% in group 1, 73.3% in group 2, and 64.3% in group 3 ($p < 0.001$). The average energy, number of shockwaves, number of sessions, retreatment rate, auxiliary procedure rate, and overall efficacy quotient were 1.76 units, 2260, 1.4, 33%, 8.2%, and 0.62, respectively.

Conclusion: SWL is an effective treatment method in selected patients in pediatric age group. However, percutaneous nephrolithotomy can be the first alternative for stones larger than $200\,mm^2$. It should also be kept in mind that the success rate of SWL decreases when the degree of hydronephrosis increases.

Introduction

Urinary stone disease is a common and significant problem in developing countries and may cause deterioration of renal function and permanent damage to the kidney. Urolithiasis is a disease that causes high morbidity. In fact, it is involved in 3.8% of children with end-stage renal disease in Turkey.[1] Minimal invasive techniques should be used to treat urinary calculi in children because of higher probability of stone recurrence than in adults. Shockwave lithotripsy (SWL) has now been accepted as the first-line treatment for most cases of urinary tract stone disease in the pediatric population because of a low percentage of complications and subsequent surgical retreatments.[2] The stone clearance rate in children treated with SWL is greater than that in adults.[3] In the present study, we aimed to assess the efficacy of a third-generation electromagnetic SWL machine in the treatment of pediatric urinary stone disease and to determine the effect of stone burden and hydronephrosis on the success rate of SWL.

Materials and Methods

In this multicenter study, 260 children (148 boys and 112 girls) with renal and/or ureteral calculi aged between 3 months and 16 years (mean: 6.7 years) were treated with the Siemens Lithostar Modularis Uro-Plus (Siemens Medical Systems, Erlangen, Germany) at a multiuser SWL center in three different hospitals between 2003 and 2009. History was taken and physical examination, urine culture, serum creatinine, and blood urea nitrogen measurements were performed in all patients. Intravenous urography (IVU), ultrasonography, or noncontrast computerized tomography was used to diagnose, locate, and define the stone burden, and the degree

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of hydronephrosis. Patients with anatomical abnormalities and staghorn stones were excluded from the study.

Children presenting with urinary tract infection received culture-specific antimicrobials before SWL was performed. Of 260 patients, 19 presented with bilateral renoureteral stones, 24 with multiple stones in the same renal unit, and 4 with a stone in a solitary kidney. There were 17 stones in the upper calyx, 34 stones in the middle calyx, 67 stones in the lower calyx, 124 stones in the renal pelvis, 30 stones in the upper ureter, 16 stones in the middle ureter, and 15 stones in the distal ureter. None of the patients had multiple ureteral calculi.

Stone burden was defined as the size of a stone measured by multiplying the largest vertical diameters by horizontal diameters in millimeters on an abdominal plain X-ray. In the presence of more than one stone in the kidney, the burden was determined by adding the sizes of each calculus. The patients were divided into three groups according to the stone burden (group 1: $<100\,mm^2$; group 2: $101–200\,mm^2$; group 3: $<200\,mm^2$) and four groups according to the degree of hydronephrosis (group 0: absent; group 1: mild; group 2: moderate; group 3: severe).

The degree of hydronephrosis was determined by IVU or ultrasonography, as previously described.[4] Effects of sex, age ($\leq$6 years, $>$6 years), stone burden, and hydronephrosis on the success rate and the retreatment rate were evaluated, and all groups were compared. Further, the average energy, number of shockwaves, number of sessions, fluoroscopy time, retreatment rate, and auxiliary procedure rate were evaluated. The medical records were used to identify post-SWL secondary treatments to calculate the efficacy quotient (EQ).

SWL treatments were performed on an outpatient basis under sedation mainly in the form of midazolam and propofol; however, general anesthesia was performed when sedation was not sufficient. An ultrasound probe and overhead module were used for radiolucent and semiopaque stones in which it would be necessary to use contrast medium for localization. Renal and ureter sessions were performed with 60 shockwaves/min. The number of the shocks was determined by the urologist, and the session was ended when stone fragmentation was achieved or the number of shocks administered was 3500.

After SWL, a plain (kidney, ureter, and bladder radiograph) film was obtained on the first day to assess the extent of stone fragmentation. If no fragmentation was seen, a second session was planned. If fragmentation was achieved, the patients were examined with another kidney, ureter, and bladder radiograph film 1 to 2 weeks later, and an additional session was planned when needed. All patients underwent IVU or noncontrast computerized tomography approximately 3 months after the last SWL session. The procedure was considered successful if the patient was stone free or had only clinically insignificant residual fragments ($\leq$3 mm) 3 months or more after the last SWL session.

The medical records of the patients were reviewed for post-SWL secondary treatments (auxiliary procedure) such as Double-J stent, ureteroscopy, or percutaneous nephrolithotomy (PCNL), which were used for calculation of the EQ according to the method described by Preminger and associates.[5] The EQ, which is a measure of SWL performance, is the percentage of patients who are stone free $\times 100 / (100\% +$ retreatment percentage $+$ percentage of auxiliary procedures). Stone characteristics (stone burden and degree of ureterohydronephrosis) were assessed in relation to the retreatment rate and success rate using chi-square test and Mann–Whitney *U*-test. *Z*-test was performed to compare the relation between sex and the success rate. $p < 0.05$ was considered significant.

Results

In 260 patients younger than 16 years, 279 renoureteral units (155 on the right and 124 on the left) were treated with 402 SWL sessions. There was no relation between sex and age and the success rate ($p = 0.537$ and $p = 0.871$, respectively). Stone size ranged from 11 to $525\,mm^2$ (average: $98.2\,mm^2$). The average stone burden was $109.7\,mm^2$ (range: 11–525) in 218 renal units and $56.6\,mm^2$ (range: 15–180) in 61 ureteral units. Thirteen stones were radiolucent. A maximum of 3500 shock waves were applied. The mean number of shock waves was 2260 ± 744 (range: 500–3500) per SWL session. The mean energy used was 1.76 ± 0.63 units. The mean fluoroscopy time was 5 ± 2 minutes. One hundred and eighty-seven patients (67%) underwent one SWL session, 61 patients (21.9%) underwent two SWL sessions, and 31 patients (11.1%) underwent three SWL sessions. The overall retreatment rate was 33%. The average number of therapy sessions for the entire patient population was 1.4. The characteristics of treatment were summarized in Table 1.

According to the stone burden, the success rate was 93.1% in group 1, 85.5% in group 2, and 60% in group 3 ($p < 0.001$). According to the degree of hydronephrosis, the success rate was 93.8% in group 0, 89.6% in group 1, 73.3% in group 2, and 64.3% in group 3 ($p < 0.001$). Further, the average success rate was 80.7% in the hydronephrotic groups (groups 1–3), but 93.8% in patients without hydronephrosis, and the difference was statistically significant ($p = 0.002$). The SWL success rate was 86.2% (188/218) for the calculi in the renal units and 91.8% (56/61) for the calculi in the ureteral units without a significant difference ($p = 0.347$). The overall success rate (stone free and only clinically insignificant fragments) for 402 SWL sessions in 279 renoureteral units was 87.5% at the end of 3 months. The overall EQ was 0.62. There was a significant decrease in EQ as stone burden increased. Although it was not clear as in stone burden, there was a slight decrease in EQ as hydronephrosis increased. The distribution of success rates by stone burden and hydronephrosis is presented in Table 2.

Table 1. Characteristics of Treatment

No. of patients (boys/girls)	260 (148/112)
Mean age (years)	6.7 (range: 3 months–16 years)
$\leq$6 years (%)	143 (55)
$>$6 years	117 (45)
Renoureteral unit	279
Right/left (%)	155/124 (55/45)
Overall stone number (*n*)	303
Overall SWL session	402
Mean stone burden (mm^2)	98.2 (range: 11–525)
Mean session	1.4 (range: 1–3)
Mean applied shockwaves	2260 (range: 500–3500)
Mean energy (units)	1.76 (range: 0.3–3.4)
Mean energy maximum (units)	2.27 (range: 0.4–4)
Mean fluoroscopy time (min)	5 (range: 0.5–12.1)

SWL = shockwave lithotripsy.

Table 2. Success According to Stone Burden and Hydronephrosis

Stone	n	*Mean stone burden (%)*	*Mean no. of treatment sessions*	*Retreatment (%)*	*No. of stone free (%)*	*No. of CIRFs (%)*	*No. of auxiliary procedures (%)*	*Success (%)*	*Efficacy quotient (%)*
Sone burden									
≤100 mm^2	173	45.2	1.3	47 (27.2)	151 (87.3)	10 (5.8)	6 (3.4)	161 (93.1)	0.71
101–200 mm^2	76	137	1.4	24 (31.6)	56 (73.7)	9 (11.8)	6 (7.9)	65 (85.5)	0.61
≥201 mm^2	30	305	2.1	21 (70)	10 (33.3)	8 (26.7)	11 (36.6)	18 (60)	0.29
Degree of hydronephrosis									
Absent	144	78.4	1.4	51 (35.4)	123 (85.5)	12 (8.3)	4 (2.8)	135 (93.8)	0.68
Mild	77	106.6	1.4	25 (32.5)	55 (71.4)	14 (18.2)	4 (5.2)	69 (89.6)	0.65
Moderate	30	134.3	1.3	7 (23.3)	21 (70)	1 (3.3)	8 (26.6)	22 (73.3)	0.49
Severe	28	137.4	1.4	9 (32.1)	18 (64.3)	0 (0)	7 (25)	18 (64.3)	0.41
Overall	279	98.2	1.4	92 (33)	217 (77.8)	27 (9.7)	23 (8.2)	244 (87.5)	0.62

CIRFs = clinically insignificant residual fragments.

Although high stone burden increased the number of SWL sessions, which in turn resulted in a significantly increased retreatment rate ($p < 0.001$), there were no correlation between the degree of hydronephrosis and the retreatment rate ($p = 0.370$).

Major clinical presentations were abdominal pain and/or flank pain in 141 children (54.3%), macroscopic hematuria in 74 children (28.4%), nonspecific complaints (e.g., fever, restlessness, lack of appetite, and failure to thrive) in 28 children (10.7%), and urinary tract infection in 41 children (15.7%). A positive family history for urolithiasis was determined in 144 children (55.3%). Double-J stents were placed initially in four patients with calculi causing complete obstruction in the urinary system, in four patients with high stone burden, and in four patients with solitary kidney before SWL. Further, SWL was performed to four patients for residual fragments whose Double-J stents were inserted in an initial open or endoscopic urinary stone surgery. Percutaneous nephrostomy catheters were inserted in two anuric infants with bilateral ureteral obstruction before SWL (Table 3).

There have been no complications during SWL sessions, and no anesthetic complications, arrhythmias, or hemoptysis were noted. Only 24 children, unable to tolerate pain, required general anesthesia. The patients were treated on an outpatient basis and discharged within 3 to 6 hours, except four patients who had acute pyelonephritis after SWL and were hospitalized and treated with parenteral antibiotics for 3–10 days. The minor complications encountered were petechiae at the site of shockwave energy, which was present in various degrees in nearly all of the patients, and early hematuria. Steinstrasse was encountered in 28 patients (10.8%). *In situ* SWL was applied in 4 of these patients, whereas 24 patients were treated conservatively. The SWL procedure was insufficient in 35 renoureteral units (12.5%). Auxiliary procedures after SWL were needed in 23 patients (8.2%). PCNL was performed in five patients in whom SWL was unsuccessful. Double-J catheters were placed in four cases. Ureteroscopy was performed in 13 patients in whom stones fell into the ureter. Open nephrolithotomy was performed in one patient. Twelve patients were treated with dissolution therapy or conservatively. Parathyroidectomy was performed in one patient for parathyroid adenoma after SWL session.

Only 82 stones were analyzed: 10 (12.2%) were composed of cystine, 5 (6.1%) of struvite, 3 (3.6%) of uric acid, 2 (2.4%) of xanthine, 1 (1.2%) of hypoxanthine, and the remaining 61 (74.5) were calcium based (calcium phosphate, calcium oxalate, and mixed calcium oxalate and phosphate).

Table 3. Clinical Presentation and Pre-Shockwave Lithotripsy Treatment of Patients with Urolithiasis

Complaints of patients at initial assessment	
Abdominal and/or flank pain (%)	141 (54.3)
Macroscopic hematuria (%)	74 (28.4)
Nonspecific complaints (%)	28 (10.7)
Urinary tract infection (%)	41 (15.7)
A positive family history	144 (55.3)
Pre-SWL treatment	
Double-J stent insertion (*n*)	16
Percutaneous nephrostomy insertion (*n*)	2

Discussion

Childhood urinary stone disease is a serious health problem with severe morbidity. Delay in the diagnosis of stones or inadequate treatment may cause damage to the renal parenchyma and renal failure by obstruction. The disease has a different pattern of presentation from that in adults and symptoms might change with age. Abdominal and/or flank pain, abdominal disturbance, and nonspecific symptoms such as vomiting and restlessness can be seen in children. Certain subpopulations of children are at greater risk of developing stone disease: children with a family history of stone disease, those with bladder dysfunction, and those with metabolic abnormalities.[6] Screening of the patients at risk at certain intervals is very important. Urinary stones should be treated by minimally invasive methods if available, such as SWL, PCNL, and chemolysis, and also metabolic investigations including stone analysis should be performed.

SWL is more difficult in children than in adults. The table of shockwave generator should be adjusted in accordance with the length of the child. Further, the child should be gently fixed to the table during SWL. Gonad protectors in an appropriate size for children should be ready before SWL sessions. Ultrasonography must be available for the SWL treatment of radiolucent stones. The focus of shockwave generator should be adjusted according to the anatomical structure of the children. Further, it is important that the shockwave generator device used in SWL in children should be more effective and should have less adverse effects. We believe that Siemens Lithostar Modularis Uro-Plus, which is a third-generation lithotripter used in each of our three centers, has a narrow focus and a large aperture allowing a high concentration of energy on the stone and reduces intestinal and skin exposure to the shockwaves. Further, availability of the equipment and ability to modify the device for children are other important factors that increase the success rate of SWL.

SWL has been shown to be effective and safe for the treatment of pediatric urolithiasis.[3] The use of SWL in adult and pediatric populations is well established in published reports. In a previous study performed in our clinics, the success rate was reported to be 79% in 2670 patients who underwent SWL with the same device.[7] The success rates reported in the literature ranges from 82% to 90.5% in pediatric urinary stone disease.[8,9] Most authors consider SWL to be particularly well suited for use in children because the child ureter is shorter than the adult ureter, the stones are relatively soft in this age group, and the urinary tract is compliant, which allows relatively large fragments to be eliminated easily.[3,10] As a matter of fact, 87.5% of the children in the present study were stone free after SWL treatment; this rate is higher than the rate of 79%, which we reported for all age groups after SWL in a previous study.

Several factors such as type of lithotripter, collecting system anatomy, stone composition, size, localization, and degree of hydronephrosis affect the success of interventional stone treatment in children. The significantly lower success rate especially in patients with high stone burden has been generally accepted.[8,9] In the present study, the treatment success rate decreased to 60% in patients with a stone area of $>200\,mm^2$, whereas the success rate was 93.1% in patients with a stone area of $<100\,mm^2$. Also, the mean retreatment rate increased to 70% in the patient group with a stone area of $>200\,mm^2$, whereas it was 27.2% and 31.6% in the groups with a stone area of $<100\,mm^2$ and 101–200 mm^2, respectively. Although more SWL sessions were performed to the patients with greater stone burden in the present study, the success rate was significantly lower in these patients. These results show that PCNL might be a valid alternative for SWL for the treatment of patients with stone burden greater than 200 mm^2.

Although the SWL success rate was lower for the stones localized in the lower calyces than the stones localized at other calyces of the kidney in adults, some studies in children revealed that the stone location had not been a predictor of the percentage of stone-free patients.[8,9,11] In our study, we used stone burden instead of stone localization due to the presence of stones in multiple localizations in the kidney and availability of performing SWL to multiple renal calculi in different localizations of kidney in the same sequence.

Whether hydronephrosis affects the outcome of SWL treatment remains controversial. Most of the studies on this issue have focused on the relation between hydronephrosis and the success rate of SWL or ureteroscopy for the treatment of ureteral calculi. Some authors have reported that stone-induced urinary obstruction reduced the success rate of SWL in treating ureteral stones,[12] but others did not.[13] In the present study, we evaluated the relation between the success rate and the degree of hydronephrosis caused by the calculi in all the renoureteral units. The diffuse hydronephrosis caused by ureteral and renal pelvis stones ($n = 185$) and focal dilatations caused by calyceal stones (upper, middle, and lower) of the kidney and, if present, pelvis dilatations were taken into account to evaluate the success rate. Focal caliectasis caused by calyceal stones of the kidney might not be as important as diffuse hydronephrosis caused by ureteral and renal pelvis stones. However, we thought that even focal dilatations caused by stones might have a negative impact on the success rate. In this study, high degrees of hydronephrosis significantly decreased the rate of stone-free patients, which was independent of stone burden. Therefore, the success rate of SWL performed for calculi causing a significant hydronephrosis might be lower than the success rate of SWL performed for calculi without any hydronephrosis. This might be attributable to the decrease in urine production of the kidney with parenchymal atrophy and deterioration of ureteral peristalsis.

We used the success rate and EQ together for evaluating the results of SWL in this study. Nowadays, EQ has been generally used in the studies concerning SWL.[7,8] Efficacy Quotient can reveal SWL outcomes better than the success rate because it takes the success rate and repeat treatment sessions into consideration and also includes other factors that might affect the success such as auxiliary procedures. Some additional factors affecting the success such as the degree of hydronephrosis and presence of clinically insignificant residual fragments might contribute to the standardization and use of the procedure.

Conclusions

The results of this study indicate that SWL treatment of urinary stones with Siemens Lithostar Modularis Uro-Plus device in children is safe and effective. We suggest that SWL should be used as the first-line treatment in children who do not have severe hydronephrosis and whose stone burden is $<200\,mm^2$. However, SWL should not be recommended as the first treatment option for the management of patients with stone burden of $\geq 200\,mm^2$ and with significant hydronephrosis.

Disclosure Statement

No competing financial interests exist.

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Abbreviations Used

CIRFs = clinically insignificant residual fragments
EQ = efficacy quotient
IVU = intravenous urography
PCNL = percutaneous nephrolithotomy
SWL = shockwave lithotripsy