Pneumatic Lithotripsy vs. Laser Lithotripsy in the Management of Proximal Ureteral Stones

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Abstract

Introduction and Objectives. Diverse lithotripsy methods for ureteral stones have been associated with ureteroscopy (URS), pneumatic lithotripsy (PL), and laser lithotripsy (LL) with Holmium: YAG (HO: YAG) laser source. These are the most ubiquitary spread techniques.

Materials and Methods. We conducted a retrospective study over six months, October 2019 - March 2020. We compare the results of 49 cases of upper third ureteral stone lithotripsy using both methods PL 26 cases (53.06%) and LL 23 cases (46.93%).

Results. Patients were followed as outpatients for 3 to 6 weeks; in cases that presented retrograde stone migration and did not achieve stone-free status, an auxiliary procedure such as shock-wave lithotripsy (SWL) or repeated URS were associated. The most prevalent intraoperative complication was represented by retrograde stone migration and postoperative by hematuria and fever. In all cases, LL had overall better results. Overall stone-free rates and need of auxiliary procedure were also in favor of LL.

Conclusions. The mean operative time and slightly increase in laser costs did not overcome the real benefits of using LL, especially for the proximal ureter. Thus we strongly consider LL a valuable weapon in the armamentarium of every urologist.

Key-words: ureteral stones, ureteroscopy, lithotripsy, pneumatic, laser

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Introduction and objectives

Nephrolithiasis represents a common finding in middle-aged adults, with a pick between the third and fifth decade of life [1]. The most incriminating risk factors in the occurrence of urinary stones include various metabolic conditions, environmental factors, socioeconomic status, and genetic predisposition [2,3]. The management of nephrolithiasis ranges from conservative (active monitoring, including expulsive therapy using various drugs) to extracorporeal shock wave lithotripsy – SWL or multiple surgical approaches. The treatment's choice is directly connected to stone size, degree of obstruction, symptoms' severity, stone location, kidney function, or urinary tract infections [4].

In the last decades, ureteroscopy (URS) has significantly changed the perspective of ureteral calculi management. We witness advances in major technical aspects such as endoscopes miniaturization, enhanced tools, or improved optical quality. Apart from common considerations regarding general anesthesia or relapsing urinary tract infections (UTIs), the European Association of Urology (EAU) guidelines recommend URS to be performed in all patients without specific contraindications (5). Peculiar aspects such as ureteral strictures may impede the ureteral retrograde approach. Various techniques are accessible for ureteral stone fragmentation - laser, pneumatic, ultrasonic or electrohydraulic lithotripsy [6-9]. The pneumatic lithotripsy (PL) uses vibrating mechanical forces for fragmentation. For many years, it has activated as a safe, practical, and cost-effective method for stone surgical management; thus, the Lithoclast has acknowledged worldwide recognition as a popular treatment modality for ureteral calculi. However, higher retrograde stone migration (RSM) represents its disadvantage [7,10]. The laser technology represents in endourological practice a major achievement in the management of urolithiasis. The method showed raising success for proximal and impacted stones, fewer intraoperative complications, and an overall better outcome for both surgeon and patient, but at a higher cost [11]. Laser lithotripsy, and especially Holmium (YAG): yttrium-aluminum-garnet – Ho(YAG) is nowadays a well-established method of intracorporeal lithotripsy with escalating popularity [12].

This study compares two methods of lithotripsy in terms of safeness and efficiency for ureteral stones, as well as complication rates.

Materials and methods

We designed a retrospective study that was conducted between October 2019 and March 2020 on both male and female patients at "Prof. Dr. Th. Burghele" Clinical Hospital in Bucharest, Romania. 49 patients who underwent semirigid retrograde ureteroscopy for upper third ureteral stones management by pneumatic lithotripter – EMS SwissLithoclastRMaster or Holmium(YAG) laser – EMS SwissLaserClastR were included. The subjects were divided into three segments: ureteropelvic junction (UPJ) 13 patients (26.53%), lumbar superior 21 patients (42.85%) and lumbar inferior 15 patients (30.61%), with stone dimensions > 5 mm and < 15 mm and negative urine cultures. The exclusion criteria were untreated urinary tract infections, coagulopathy, acute renal failure, concurrent middle or lower ureteral calculi, or loss of follow-up. In all cases, the stone size and upper urinary tract topography were evaluated by computer tomography (CT) or intravenous urography (Fig. 1.A & 1.B), the dimension of the stone was defined as the longest measurable diameter on imaging. Three weeks after the surgery, all patients had a kidney-ureter-bladder (KUB) X-ray (Fig. 1.C). Stone retrograde migration was considered when a fragment larger than 3 mm was pushed back into the kidney. Postoperatively, the diagnosis was completed with KUB X-ray for radiopaque calculi and non-contrast computerized tomography (NCCT) for radiolucent ones. No stone larger than 3 mm visible after three weeks was defined as a stone-free outcome.

The preoperative evaluation comprised the complete medical history and a clinical examination in all patients. Complete blood count (CBC), urinalysis, and urine culture were also evaluated. Stone location and upper urinary tract topography were investigated through abdominal and pelvic ultrasound, intravenous urography, or CT urogram. Renal function parameters were obtained in all patients. In addition, coagulogram and blood sugar were examined. Senior surgeons performed all procedures. Surgeries were undertaken either by spinal or general anesthesia. All patients received a prophylactic single-dose wide-spectrum intravenous antibiotic before surgery (1 g of ceftazidime 1 h before surgery). In 12 cases (24.48%), patients had a double-J stent placed preoperatively, which was extracted at the beginning of the operation, while on 2 cases (4.08%), patients had a nephrostomy tube put which was removed after 24 h. Procedures were undertaken with patients placed in a lithotomy position. In all cases, procedures were performed under fluoroscopic guidance and the protection of a nitinol guidewire.

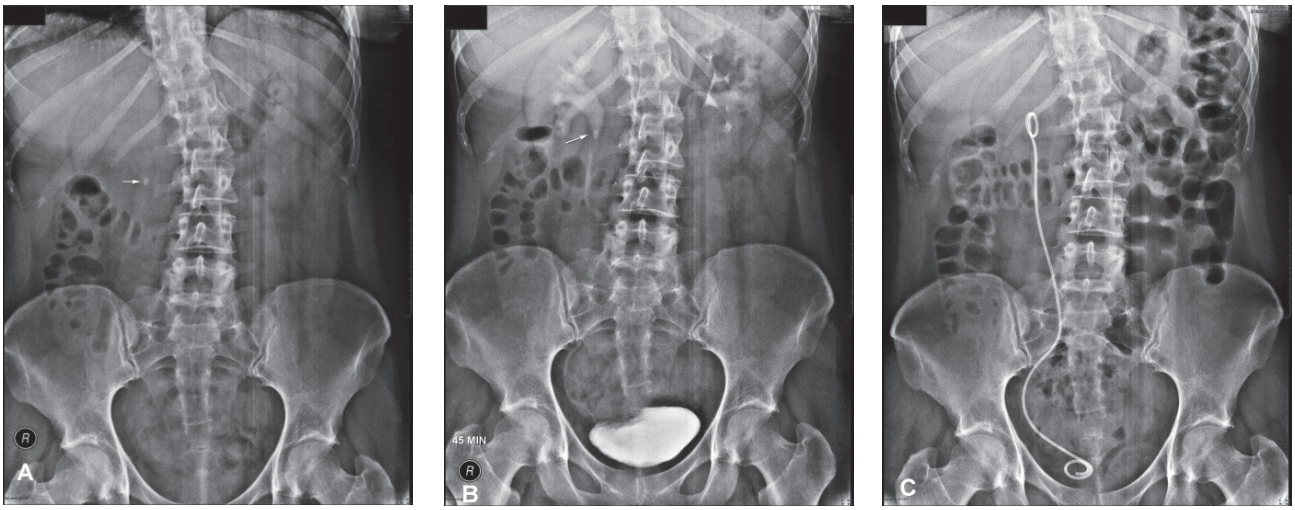

Figure 1
A. Right kidney UPJ stone 8 mm diameter on KUB;
B. Right kidney UPJ stone on intravenous urography after 45 minutes post-contrast media with delayed excretion of the right kidney due to prolonged obstruction;
C. Post-procedure double-J stent on follow-up KUB

A Wolf (Knittlingen, Germany) semirigid ureteroscope (6.5/7.5 Ch/Fr; 7/8.5 Ch/Fr) was utilized in all cases. For pneumatic lithotripsy, we used an EMS SwissLithoClastRMaster with 0.8 mm and 1 mm probes, respectively; settings were frequency 5 Hz, energy 4 bar, in either single-shot pulse or continuous pulse. For laser lithotripsy we used Ho:YAG laser from an EMS SwissLaserClastR source, with a 320 um fiber that was advanced through the working channel of the ureteroscope to the surface of the stone; different settings were used for different expected results: dusting - long pulse, low energy 0.5 J, high frequency 15-20 Hz, power 7.5-10 W; fragmentation - short pulse, high energy 1.5-2 J, low frequency 8 Hz, power 7.5-12 W; pop-corn - long pulse, high energy 1-1.5 J, 10-15 Hz, power 10-17.5 W.

In either group, baskets or cone tubes were not used as prevention for retrograde migration of the stone. All stones were entirely fragmented into smaller parts; larger stone fragments were extracted with forceps. In the end, all patients received a double-J stent for 1 to 2 weeks, depending on intraoperative events. Bleeding, presence of ureteral strictures that required progressive dilatation up to 10-12 Ch/Fr, edema at the stone impact site, perforation of the ureter, retrograde migration of a residual stone fragment, granulation formation at fragmentation site, or the burden of remaining particles are the most common complications. All patients are considered as outpatients and are followed at three weeks, six months, and annually with renal and pelvic ultrasound and KUB. Patients with retrograde migrated stone fragments that failed to expulse spontaneously underwent auxiliary procedures such as repeated URS or SWL; the latter was performed two weeks after the initial operation.

The follow-up for all patients ranges from 3 to 6 weeks and begins in postoperative day 1. We recorded any peculiar symptoms such as hematuria, loin pain, fever / chills, or irritative symptoms. Complications were indexed according to the Clavien Classification of Surgical Complications [13]. The patients' sex, age, stone dimension, preoperative double-J or nephrostomy tube insertion, retrograde migration, stone-free rate (SFR), secondary intervention (SWL or URS), rate for residual stones, and complication rate (Clavien Grades) were recorded.

Data were analyzed using Microsoft – Excel software, and simple descriptive statistics were calculated. Frequency and percentage were determined for certain variables.

Results

A total of 49 patients (with a male : female ratio of approximately 2.06:1) underwent semirigid retrograde ureteroscopy (URS) for lumbar ureteral stones. In 26 (53.06%) patients, pneumatic lithotripsy (PL) was the mean of fragmentation, while in 23 (46.93%) of them laser lithotripsy (LL) was the procedure of choice. The patients' mean age that underwent PL and LL was 45.53 years (21-72 years) and 52.65 years (20-78 years), respectively. Urinary tract infections (UTIs) represent a key element in the occurrence and physiopathology

of nephrolithiasis. We observed that 27 (55.10%) of all patients stated they experienced at least one episode of UTIs in their life, the incriminated pathogens being represented by E. coli in 30.61%, followed by Proteus in 7 cases (14.28%), Klebsiella spp. in 3 cases (6.12%) and Enterococcus spp. in 2 cases (4.08%). History of nephrolithiasis was quite common; 18 (36.73%) mentioned they had been diagnosed with renal stones in the past.

The detailed clinical and demographic characteristics of both groups are represented in Table 1.

Table 1. Demographic and Clinical Characteristics

Variable	PL		LL		Total	
	no.	%	no.	%	no.	%
Mean age	45.53		52.65		48.87	
Sex						
Male	18	69.23	15	65.21	33	67.34
Female	8	30.76	8	34.78	16	32.65
Stone laterality						
Right side	13	50.0	10	43.47	23	46.93
Left side	13	50.0	13	56.52	26	53.06
Stone location						
UPJ	2	7.69	11	47.82	13	26.53
Lumbar superior	14	53.84	7	30.43	21	42.95
Lumbar inferior	10	38.46	5	21.73	15	30.61
Mean stone dimension	9.84 mm		10.39 mm		10.10 mm	
Preoperative drainage						
Double-J stent	6	23.07	7	30.43	13	26.53
Nephrostomy tube	2	7.69	1	4.34	3	6.12

In some cases, intraoperative events have occurred. We documented any significant stenosis that required progressive dilatation up to 10-12 Ch/Fr, still allowing the surgeon to continue the procedure. An important edema at the impaction site, the accidental perforation of the ureter, or stone migrations at different maneuvers were also noted. We encountered an overall of 6 cases (12.24%) with considerable stenosis that required ureteral dilatation, of which 5 cases (19.26%) in PL group and 1 case (4.34%) in LL group. In PL group, in 4 cases (15.38%), the ureteral stenoses were diagnosed in males and only 1 (3.84%) in a female. In LL group, the single case (4.34%) of ureteral stricture was encountered in a male patient. In all cases, ureteral stenosis that required dilatation represented an indication of extended postoperative ureteral catheterization.

Mucosal edema at the impaction site of the stone was found in 24 cases (48.97%) in overall patients; in the PL group, it was detected in 16 patients (61.53%), whereas in the LL group in 8 cases (34.78%). Preoperative ureteral stenting with a standard double-J may induce edema. In the PL group, 18 cases (69.23%), not previously stented, and only two patients (7.69%), stented, presented ureteral edema. In the LL group, six unstented patients (26.08%) showed ureteral edema compared to only two previously stented patients (8.69%).

Two cases (4.08%) complicated with ureteral perforation during fragmentation maneuvers, both done by pneumatic lithotripter. None was encountered amid laser fragmentation. The ureteral lesions were managed conservatory, extending the postoperative stay for the double-J stent. We had no extraureteral stone migration.

Retrograde stone migration (RSM) represents a key element in the stone-free outcome, which resumes the overall success of the procedure and also the main purpose of any lithotripsy-targeted surgery. We report 20 cases (40.81%) from all patients. In the PL group, it was observed in 15 patients (57.69%), while in the LL group, only in 5 cases (21.73%). We documented the relationship between the stone location at different ureteral levels and the incidence of stone migration. In the PL group, both of the two calculi (100%) situated at the UPJ have migrated into the renal collecting system. In one case, catching the stone fragment with a Dormia basket and further fragmentation with forceps extraction of the remaining smaller fragments were possible. Still, in the other case, the fragment migrated

into the inferior calyx, with the impossibility of further maneuvering. It is a criterion of not achieving stone-free status, and secondary intervention was needed; in this particular case, the surgeon performed flexible URS with HO:YAG laser fiber.

RSM occurred also for calculi situated lumbar superior: 11 in 14 cases (78.57%), and lumbar inferior: 2 in 10 cases (20.0%). In the LL group, RSM was detected in stone situated at UPJ 4 in 11 cases (36.36%), at the in lumbar superior: 1 in 7 cases (14.28%) and inferior lumbar, 0 in 5 cases. Also, we consider important the relationship between the degree of renal collecting system dilatation and RSM; in the PL group - 4th degree of dilatation presented 2 in 2 cases (100%) of stone migration; 3rd degree of dilatation: 3 in 6 cases (50.0%); 2nd degree of dilatation: 5 in 8 cases (62.5%); 1st degree of dilatation: 2 in 5 cases (40.0%). In the LL group - 3rd degree of dilatation: 1 in 2 cases (50.0%); 2nd degree of dilatation: 1 in 6 cases (16.66%); 1st degree of dilatation: none in 8 cases.

Different stone sizes imply diverse outcomes. All 49 patients enrolled in this study presented stone dimensions between 5 mm and 15 mm. We divided patients into two separate groups based on stone dimension, one group that presented stones between 5 mm and 10 mm and one group for stones larger than 10 mm (Table 2 and Table 3).

Table 2. Outcomes in patients with stones ≤ 10 mm

Characteristics	PL		LL		Total	
	no.	%	no.	%	no.	%
Procedures no.	16		13		29	
Males	9	56.25%	9	69.23%	18	62.06%
Females	7	43.75%	4	25.0%	11	37.93%
Mean stone size	8.31 mm		8.69 mm		8.48 mm	
Retrograde stone migration	10	62.5%	2	12.5%	10	34.48%
Postoperative hematuria	11	68.75%	4	25.0%	15	51.72%
Postoperative fever/chills	2	12.5%	0	-	8	27.58%
Stone free rate	7	43.75%	10	62.5%	17	58.62%
Secondary intervention rate	2	12.5%	1	6.25%	3	10.34%

Table 3. Outcomes in patients with stones >10 mm

Characteristics	PL		LL		Total	
	no.	%	no.	%	no.	%
Procedures no.	10	NA.	10	NA.	20	NA.
Males	9	90.0%	6	60.0%	15	75.0%
Females	1	10.0%	4	40.0%	5	25.0%
Mean stone size	12.3 mm		12.6 mm		12.45 mm	
Retrograde stone migration	5	50.0%	3	30.0%	8	40.0%
Postoperative hematuria	6	60.0%	4	40.0%	10	50.0%
Postoperative fever/chills	2	20.0%	1	10.0%	9	45.0%
Stone free rate	6	60.0%	8	80.0%	14	70.0%
Secondary intervention rate	3	30.0%	2	20.0%	5	25.0%

Hematuria and fever are the most relevant early postoperative complications in patients that underwent URS. We considered hematuria any alteration of urine color into different shades of red and fever as any rise of the temperature above 38o C in the absence of any other cause except surgery-related ones. The severity of hematuria oscillated from mild to moderate, no case of abundant hematuria was present. In all cases, both hematuria and fever were treated conservatory, lasting from 24h to maximum 48h; they also represented criteria of prolonged ureteral stenting, up to a maximum of 2 weeks.

Hematuria was observed in 25 patients (51.02%); in PL group –17 patients (65.38%), and in LL group – 8 patients (34.78%). The presence of ureteral edema at the stone impaction site frequently relates to a variable degree of postoperative hematuria. In the PL group – 13 in 16 (81.25%) patients with ureteral edema have complicated with some sort of hematuria and only 4 in 10 patients (40.0%), without edema. In the LL group, 7 in 8 patients (87.5%) presenting ureteral edema have positively resulted in different degrees of hematuria, and only 1 in 15 patients (6.66%) lacking edema.

Postoperative fever was overall observed in 5 patients (10.20%); in PL group – 4 patients (15.38%); in LL group – 1 patient (4.34%). Fever was associated with the absence of preoperative stenting. Postoperative hematuria is linked to ureteral edema, also related to the lack of preoperative urinary stenting. Thus, we acknowledge that preoperative drainage by either a double-J internal stent or a nephrostomy tube can significantly reduce postoperative hematuria or fever.

The most desired result of lithotripsy-targeted URS is a SFR; in selected cases, when SFR could not have been achieved, an auxiliary procedure has been required. Higher SFR was attained in the LL group, resulting in a reduced number of further interventions for the patient. Detailed data regarding SFR and auxiliary procedures, as well as operating time, are represented in Table 4. In the PL group – 2 in 4 cases (50%) necessitated a flexible instrument caused by RSM in the inferior calyx, as auxiliary URS.

Table 4. Comparative results in study group

Parameters	LithoclastR2 (n=26)	HO:YAG laser (n=23)
Stone-free rate (%)	13 (50%)	18 (78.26%)
Mean operative time	42.5 min	65.21 min
Fragments requiring auxiliary procedure	5 (19.23%) URS - 4 SWL - 1	3 (13.04%) SWL – 2 URS - 1

HO:YAG = holmium:yttrium- aluminum-garney;
URS = ureteroscopy; SWL = shock-wave lithotripsy

Discussions

Accessing the upper third ureteral segment with rigid and large instruments is difficult. It makes ureteroscopy the second-line treatment after extracorporeal shock-wave lithotripsy. Advances in technology represent a key element in the rising number of ureteroscopic procedures performed for proximal ureteral stones. Intracorporeal lithotripsy is mostly realized by laser or pneumatic effect. The principle of the holmium laser is represented by photothermal energy, limited to half of a millimeter penetration, that is used to fragment stones (14). Pneumatic or "ballistic" lithotripsy is comparable to a pneumatic jackhammer that uses pushing force directly on the stone to fragment it into smaller pieces (15). Thus, the probability of SRM, especially for the upper third ureteral stone, rises with reducing the SFR and so the overall success of the procedure, comparing to laser lithotripsy [16-19].

Considering UTIs an important element in the medical history of a lithiasis patient, we observed E. coli to be the most frequent uropathogen, followed by Proteus spp., Klebsiella spp. and Enterococcus spp. Last year we conducted a survey to determine the incidence of uropathogens among Romanian patients and their resistance to common antibiotics used to treat them (20). We observed the highest rate of uropathogens to be the same in both lithiasis and non-lithiasis patients, except for Proteus spp. which ranks second in the lithiasis population; its key role in stone pathogenesis is well known [21,22].

A ureteral stricture is one of the essential elements of difficulty in ureteroscopic ascending. These results are similar to other Romanian studies [23]. Mucosal edema at the stone impaction site also represents a key factor of intraoperative complications and a veritable predictor of postoperative hematuria. Kim S.W. et al. [24] recently published research on 204 patients that underwent ureteroscopic lithotripsy and reported similar results. They presented identical preoperative grades of hydronephrosis. This highlights the hypothesis of a close relationship between the lack of preoperative stenting and hydronephrosis occurrence, edema, and other surgical complications. Similar findings were previously demonstrated [25,26]. Ureteral perforation represents a severe

complication that can lead rapidly to decreasing the overall progression; in all 2 cases (4.08%), it produced double-J stent extended period of insertion with proper antibiotic cover. Our findings are quite similar to other studies. Ibrahim K.A. reported results of a prospective study where 4 in 148 patients (2.7%) experienced ureteral perforation [27]. Mandal S. et al. concluded that the overall incidence of ureteral perforation varies between 1.6% and 6.25% [28]. The vast majority of cases seem to be related to the relative dimension of the stone [29]. Stone migration in the proximal segment of the ureter represents one of the most common complications, especially in pneumatic lithotripsy [29]. Aridogan et al. [30] also demonstrated that ureteral stones located in the proximity of the UPJ have higher chances of retropulsion (29%) compared to the middle or distal ones (6%) due to shorter distance to the renal collecting system. El-Nahas et al. (31) presented similar results, stating that 35% of proximal ureteral stones show higher rates of migration. The lack of research on the upper third of the ureter impedes the process of comparing results. The closeness of stone located at this level to the UPJ endorses a rapidly retrograde migration as our results have shown, in 40.81%. The "jackhammer" effect of PL compared to the photothermal one of LL, raises the possibility of retrograde migration, as multiple studies have previously stated [32-34].

The overall rate of URS complications varies between 10 and 30 percent. Major complications such as sepsis, ureteral stricture, or avulsion are lower than 0.1% [5]. We did not experience any of the major complications, only Clavien I and II grade, that were treated conservatively and subsided in less than 48h. It represented a reason for an extended period of ureteral stenting. Hematuria and fever were our only complications. Mahmood S.N. et al. [35] have recently presented a study on 100 patients and also concluded that PL presents a higher rate of postoperative hematuria. Bapat S.S. et al. [36] also demonstrated that LL shows lower rates of hematuria compared to PL and also could offer a good alternative for patients presenting bleeding diathesis. He reports LL in patients receiving anticoagulants. The method did not increase the risk of hematuria and also can limit the risk of thromboembolic complications without preoperative corrections of bleeding parameters in these patients [37,38]. Fever was also a minor complication that resolved itself in less than 48h without any treatment. Several studies have presented similar results to ours, considering fever as a postoperative complication [39,40]. We also observed a strong connection between preoperative urinary stenting and reducing the incidence of fever. However, a recent study by Nevo A. et al. [41] on 601 patients has warned us about the possibility of the rising prevalence of sepsis based on prolonged preoperative indwelling catheters in URS. More prospective studies on this thesis should be undertaken.

SFR were comparable to other findings in the literature, all authors admitting that the success rate for the upper third of the ureter is lower compared to the other segments [42-44]; LL also presents higher rates of SFR comparing to PL [45]. The mean operative time, higher in LL compared to PL, is correlative to other findings (46-48); this element can represent an important negative aspect on the overall management of the surgery from both perspectives, the implications on patient's health and the ergonomics of the surgeon.

Recent papers have reported promising results with the use of various stone cones to prevent retrograde migration of fragments, improving SFR and, therefore, the overall success of the procedure. We did not use any device to prevent proximal migration; a prospective study using different techniques such as stone cones for improving SFR would be useful, and it can represent the base of future investigations. This study presents several limitations. The operations were performed by different surgeons with a variable experience in endourology that can lead to bias in the results and also the retrospective character of the study; we recommend randomized prospective studies for confirmation of our results.

Conclusions

We recognize the efficiency and safeness of both lithotripsy methods but with several advantages for HO:YAG lithotripsy. The benefits are evident in dealing with upper third ureteral segment lithiasis, both in intraoperative management such as retrograde stone migration and postoperative complications like the presence of hematuria and fever. It is also superior in terms of stone-free rates and the need for auxiliary procedures. Although the cost of LL is slightly higher comparing to PL, the short learning curve for using LL as an intracorporeal lithotripter and its better overall outcomes for proximal ureter makes it a real advantage in the armamentarium of every urologist.

Conflict of Interest
The authors declare no conflicts of interest.

Abbreviations:

CT – computed tomography
HO: YAG – Holmium: YAG
KUB – kidney-ureter-bladder
LL – laser lithotripsy
NCCT – non-contrast computerized tomography
PL – pneumatic lithotripsy
RSM – retrograde stone migration
SFR – stone-free rate
SWL – shock-wave lithotripsy
URS – ureteroscopy
UPJ – ureteropelvic junction
UTIs – urinary tract infections

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