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Negative-Pressure Ureteroscopic Holmium-YAG Laser Lithotripsy for Ureteral Stones

Zhong-Hua Wu Tong-Zu Liu Xing-Huan Wang Yong-Zhi Wang
Hang Zheng Yin-Gao Zhang Xin-Hua Zhang

Department of Urology, Zhongnan Hospital of Wuhan University, Wuhan, China

Keywords
Lithotripsy · Ureteral stone · Ureteroscopy · Negative pressure · Holmium-YAG laser

Abstract
Objectives: The aim of this study was to describe a novel negative-pressure laser lithotripsy device to overcome the deficiencies of the conventional procedure. ***Patients and Methods:*** Between August 2018 and March 2019, 78 patients with a single ureteral stone underwent retrograde ureteroscopy with a Wolf 8F/9.8F rigid ureteroscope and a 200-μm holmium-YAG laser. The mean stone size was 11.8 mm, measured for the maximum length. The negative-pressure laser lithotripsy device consists of an F5 ureter catheter and a T joint. The closed tip of an F5 ureter catheter is cut off, and it is then inserted within one opening of the T joint. The 200-μm laser fiber is introduced into the ureteral catheter through the other opening of the T joint. The third opening of the T joint is connected to the negative-pressure pipe. The valve end of the Foley catheter is used for sealing the cap. Continuous suction and active irrigation throughout the lithotripsy could maintain adequate visibility. ***Results:*** All ureteroscopic procedures were successful. The negative-pressure device showed good stone retention capabilities, with no observed stone migration. We did not observe any major complications. The stone-free rate was 97.44% (76/78), demonstrated on plain radiography of the kidney-ureter-bladder on the first postoperative day. The stone-free rate after 1 month was 100%. ***Conclusions:*** The negative-pressure ureteroscopic lithotripsy is easy and safe management for the ureteral stones. It might reduce the risk of stone fragment retropulsion, improve surgical vision, shorten the operative time, and decrease the renal pelvic pressure.

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Introduction

Ureteroscopic lithotripsy is considered by many urologists to be a first-line treatment option for the management of ureteral stones. The main problem with ureteroscopic lithotripsy is stone and stone fragment retropulsion that occurs in 3–15% of distal ureteral stone cases and 28–48% of proximal stone cases [1].

Zhong-Hua Wu, Tong-Zu Liu, Xing-Huan Wang, and Yong-Zhi Wang contributed equally to this work.

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Zhong-Hua Wu
Department of Urology, Zhongnan Hospital of Wuhan University
Donghu Road #169, Wuchang Dist., Wuhan, Hubei 430071 (China)
daydreamwu@sina.com

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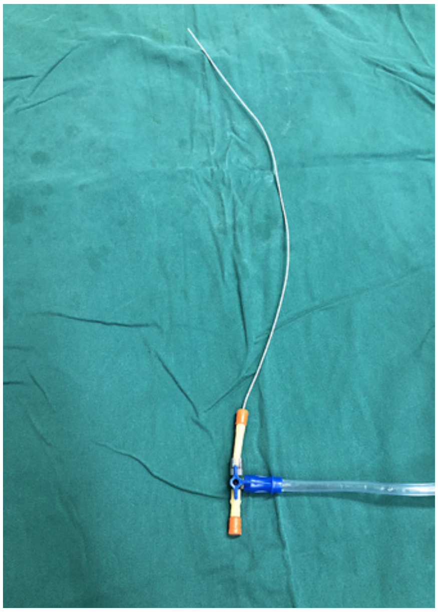

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Fig. 1. The negative-pressure laser lithotripsy device consists of an F5 ureter catheter and a T joint.

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Fig. 2. The 200-μm fiber is introduced into the ureteral catheter through the other opening of the T joint. The valve end of the Foley catheter is used for sealing the cap.

Stone and fragment retropulsion increases operative time, costs, and the number of secondary procedures, such as shock wave lithotripsy, flexible ureteroscopy, and percutaneous nephrolithotomy. Several devices (wire-, balloon-, and gel-based devices) designed to prevent stone and fragment retropulsion are currently available in the market but have certain limitations in terms of maneuverability, cost, and complications [2–5]. To increase the efficacy and reduce retropulsion during ureteroscopic lithotripsy for ureteral stones, we herein describe an easy and safe technique, which could overcome the deficiencies of the conventional procedure.

Patients and Methods

Between August 2018 and March 2019, 78 patients (42 males and 36 females) with a mean age of 42 years (range 20–77) and a single ureteral stone (45 left and 33 right) underwent retrograde ureteroscopy with a Wolf 8F/9.8F rigid ureteroscope and a holmium-YAG laser. All patients underwent preoperative plain radiography of the kidney-ureter-bladder (KUB) and abdominal noncontrast-enhanced computed tomography. The mean stone size was 11.8 mm (range 5–19 mm), measured for the maximum length. Among these patients, there were 31 stones located in the upper ureter, 22 in the middle ureter, and 25 in the distal ureter.

All ureteroscopic procedures were performed using an 8F/9.8F Wolf rigid ureteroscope under general anesthesia. In the routine lithotomy position, the ureteroscope was introduced into the bladder through the urethra under direct vision and directed to the affected ureteric orifice. Then, a 0.035-inch hydrophilic soft guide wire (Cook Medical, Bloomington, IN, USA) was then inserted into the affected ureter to facilitate the ureteroscope passage. The ureteroscope was passed over the guide wire and advanced into the ureter just below the stone. In 5 of the cases, a safety guide wire was used due to severely impacted ureteral stones or ureteral tortuosities.

The negative-pressure laser lithotripsy device consists of an F5 ureter catheter and a T joint (Fig. 1). The closed tip of an F5 ureter catheter was cut off, a side hole was snipped, and it is then inserted within one opening of the T joint. The 200-μm fiber is introduced into the ureteral catheter through the other opening of the T joint. The third opening of the T joint is connected to the negative-pressure pipe. The valve end of the Foley catheter is used for sealing the cap (Fig. 2). The ureteral catheter of our negative-pressure device was then inserted through working channel just beyond the ureteroscope. This could efficiently provide a continuous flow where the irrigation fluid coming out of the ureteroscope was immediately extracted through the ureteral catheter. It was almost the same principle used in the continuous negative-pressure suction of ultrasonic lithotripsy. Continuous suction and active irrigation throughout the lithotripsy could maintain adequate visibility.

Gravity-based irrigation paired with handheld syringe irrigation was employed. We used the force of gravity to maintain the irrigation fluid by placing a saline bag 30 cm above the level of the patient. In the presence of our negative-pressure device in the working channel, gravity-based irrigation did not provide sufficient force and fluid to secure visualization. At this time, switching to handheld syringe irrigation for on-demand flushing was in or-

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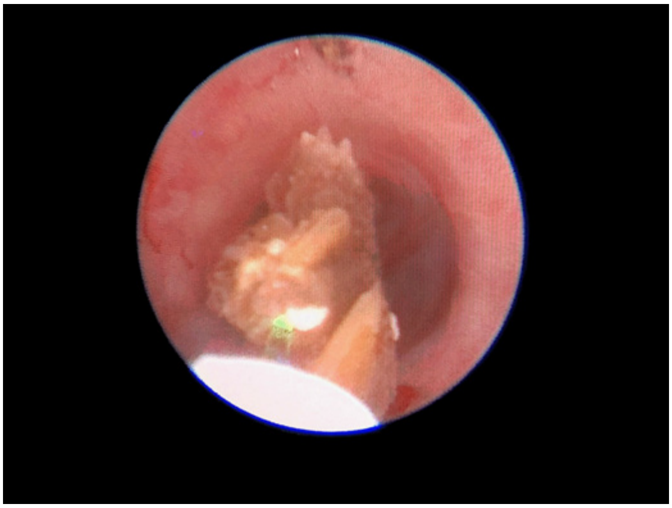

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Fig. 3. A 200-μm holmium-YAG laser is used for fragmenting the stones through the ureteral catheter.

der. We kept a minimum irrigation volume, just enough for ensuring visibility, to secure low renal pelvic pressure. Regulation of the negative-pressure suction could keep the slight collapse of the ureter wall around the operative field and limit the risk of high pressure in the operative zone.

Lithotripsy was performed using a 200-μm holmium-YAG laser in all cases, with an energy level of 0.6–1.0 J and a frequency of 12–15 Hz (Fig. 3). A higher frequency of 15 Hz was only used for the central part of large impacted ureteral stones in a short period of time to avoid ureteral wall damage. Stone fragments were either left for spontaneous passage or removed with our negative-pressure ureteral catheter.

An F4.7 double J ureteral stent (Cook Medical, Bloomington, IN, USA) was inserted after the procedure. Patients were evaluated on the first postoperative day and 1 month after surgery with plain radiography of KUB for residual stone fragments. Stone-free rate was defined as no stone fragment evident visually on the KUB. Data collected included patient characteristics, operative time (from the insertion of the ureteroscope to the positioning of the double J ureteral stent), and complications (Table 1).

Table 1. Patient demographics and operative results

Parameters	Value
Patients, *n*	78
Male/female	42/36
Mean age, years	42 (range 20–77)
Mean BMI, kg/m^2	24.6±2.12
Mean stone size, mm	11.8 (range 5–19)
Left/right	45/33
Stone location	
Upper ureter	31
Middle ureter	22
Distal ureter	25
Operative duration, min	35.8±6.44
Transfusions, *n*	0
Complications	
Slight fever after surgery	1
Ureteral perforation	0
Ureteral avulsion	0
Peripheral organ injury	0
Conversion to flexible ureteroscopy or PCNL	0
Stone-free rate on the first postoperative day	97.44% (76/78)
Stone-free rate at 1 month after surgery	100%

PCNL, percutaneous nephrolithotomy.

Results

All ureteroscopic procedures were successful. During ureteroscopic lithotripsy, the negative-pressure device showed good stone-retention capabilities, with no observed stone migration. We did not observe any major complications. One patient who developed a slight fever after surgery, due to poor infection control before operation, resolved with antibiotic therapy. No other complications, including ureteral perforation or obvious bleeding, were encountered. Conversion to flexible ureteroscopy or percutaneous nephrolithotomy was not required in any of the cases. The primary stone-free rate of the negative-pressure ureteroscopic lithotripsy was 97.44% (76/78), demonstrated on plain radiography of the KUB on the first postoperative day. The stone-free rate after 1 month was 100% (Table 1).

Discussion

Ureteroscopic lithotripsy is highly effective for both proximal and distal ureteral stones with minimum morbidity and is the first-line treatment in many urological centers. Holmium-YAG laser is one of the most popular laser lithotripters and has many advantages of fragmenting stones of all compositions, low retropulsion rates, and breaking stones to smaller fragments than most other energy sources for lithotripsy [6]. Ureteroscopic holmium-YAG laser lithotripsy is the preferred method for intracorporeal ureteral stone treatment. During ureteroscopic laser lithotripsy, the main problem is retrograde stone or stone fragments migration. It has been reported that 3–15% of distal ureteral stones and 28–48% of proximal ureteral stones undergo retrograde retropulsion [1].

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Stone retropulsion during ureteroscopic lithotripsy results in increased operative time, increased procedure cost, and additional procedures.

Several commercially available devices have been developed to prevent retrograde stone migration and assist with fragment extraction. These devices include XenX™, Stone Cone™, Accordion™, Escape™, Lithocatch™, Lithovac™, Passport™, and NTrap™ [4, 5]. Therefore, a large caliber ureteroscope (8.5F/11.5F; Richard Wolf, Knittlingen, Germany) with dual large operating channels is often used to allow simultaneous passage of an anti-retropulsion device and a laser fiber at the same time [7], although a small caliber ureteroscope (6.5F/8.5F; Richard Wolf, Knittlingen, Germany) has been developed with 2-channel continuous irrigation system that improves visibility and reduces stone retropulsion [8]. While these anti-retropulsion devices achieve some level of effectiveness, they have few flaws. The backstops of these devices require that a wire or catheter remains in the ureter, obstructing the operative field and potentially inhibiting ureteroscope maneuverability. Furthermore, risk of laser damage to the device should be considered because laser damage could prevent the device closure and extraction [2].

Other technologies include BackStop™ (a reverse thermosensitive polymer) and lubricating jelly. These devices are instilled beyond the stones in the ureter, forming a temporary plug in order to prevent stone retropulsion [3]. However, inserting a catheter around the stone without pushing it up in the ureter is not always easy. Also, this technique has the potential to wash away the gel and impair visibility during ureteroscopic lithotripsy [9].

Several studies had assessed the effectiveness of using ureteral access sheath during ureteroscopic lithotripsy. It provided access to facilitate the ureteroscope in and out of the ureter and extracting stone fragments, improving visibility and decreasing pressure during ureteroscopic irrigation. Nevertheless, the use of ureteral access sheath could harm the ureter and contribute to postoperative persistent hematuria, urinary extravasation, and even ureteral stricture [10], which precluded its routine use during ureteroscopy.

A disadvantage of using the holmium-YAG laser is that the stone retropulsion may occur, although obviously less frequently than with other energy sources for lithotripsy. We modified the standard ureteroscopic laser lithotripsy by applying the similar principles used in ultrasonic lithotripsy with simultaneous suction and fragmenting stones, which can decrease ureteral and renal irrigation pressure [11]. We inserted an F5 ureteral catheter in the ureteroscope and connected it to a negative-pressure aspirator. The key feature of the negative-pressure laser lithotripsy device is that it allows inflow and outflow (the inflow is through the ureteroscope working channel and the outflow is through the ureteral catheter).

In our suction-laser lithotripsy, we initially inserted the laser fiber through the ureteroscope working channel outside the 4F ureteral catheter and experienced failures due to clogging of the ureteral catheter by stone fragments in several patients. Since then, we started the practice of the laser fiber placement inside the ureteral catheter to eliminate clogging of the ureteral catheter. However, the 4F ureteral catheter lumen was almost occupied by the 200-μm laser fiber, failing to generate the negative pressure. We found that the 5F ureteral catheter was suitable for the 200-μm laser fiber placement to produce negative pressure because the inner diameter of the 5F ureteral catheter was 890 μm and the total diameter of the 200-μm laser fiber is 420 μm. During lithotripsy, the laser fiber can be pulled back and forth to keep the ureteral catheter unobstructed. On the other hand, a small space between the 8F/9.8F ureteroscope and the 5F ureteral catheter was available, which was just enough for irrigation.

With the continuous suction and active irrigation throughout the lithotripsy, the slight ureteral mucosa hemorrhage and the dust storm caused by fragmenting stone would no longer blur the vision; thus, the vision field is improved. Furthermore, the continuous suction with the holmium-YAG laser can draw stone fragments back to aggregate at the suction nozzle of the catheter, leading to a quicker and better stone fragmentation. Laser energy can be applied continuously without moving stones. Also, irrigation flow produces a vortex or turbulence at the tip of the ureteroscope by using continuous suction, and no pressure is cephalad transmitted, which would reduce the pressure within the renal pelvis and increase the safety of operation. It is because, during ureteroscopic lithotripsy, prolonged renal pelvic pressure beyond the normal range increases the risk of urinary reflux into the bloodstream through pyelovenous backflow and is a risk factor for postoperative infection [12, 13].

Higher energy theoretically affords greater fragmentation result; however, there are contradictions in the available data regarding the effect of fiber diameter on fragmentation result. Some authors found no relationship between fiber diameter and lithotripsy performance [14]. Moreover, some researchers considered that larger fibers ablate less than smaller fibers [15].

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We selected 200-μm holmium-YAG laser with high-frequency and low-energy settings to break up the stones into smaller fragments for spontaneous passage. Ureteroscopic laser lithotripsy has 2 techniques, dusting and fragmentation with basketing, and both are effective for ureteroscopic stone management. According to an individual stone's composition, surgeons often prefer to use a combination of the 2 techniques to acquire optimal efficiency and outcomes [16]. Recently, a new laser pulse variation, Moses technology, was introduced, which has been demonstrated in vitro and in vivo studies to significantly decrease stone retropulsion and to improve laser lithotripsy efficiency, especially at high-frequency, low-energy settings for dusting stone [17]. On the other hand, long-pulse lithotripsy has been proven to increase stone disintegration and reduce stone retropulsion compared to short-pulse lithotripsy [18]. Besides, thulium laser has been explored as the next generation technology of laser lithotripsy. Compared with holmium-YAG laser, thulium fiber laser has the apparent advantages, including a smaller fiber diameter as small as 50 μm, greatly reduced stone retropulsion, and a several times higher dusting rate [19]. These new properties may become particularly beneficial to our negative-pressure device.

Our negative-pressure laser lithotripsy device had other advantages. It required no other special equipment and no additional training. We performed negative-pressure ureteroscopic laser lithotripsy in a total of 78 patients. Surgery in all cases was successfully performed within a reasonable time without occurrence of stone migration.

Since it is only our initial experience, we do recognize the limitations of this study. One of the main limitations is the lack of renal pelvic pressure measurement. In previous studies, the renal pelvic pressure has been measured in patients with a nephrostomy tube drainage for several weeks, or by an antegradely inserted catheter during semirigid ureteroscopy in pigs or a retrogradely inserted 4F ureteral catheter during flexible ureteroscopy in humans [20, 21]. Therefore, we plan to measure the renal pelvic pressure using a similar approach during our negative-pressure ureteroscopy in order to evaluate the effect of our negative-pressure device on reducing the renal pelvic pressure. In addition, this study is the lack of a comparison group; thus, a prospective, randomized study is needed to determine whether the negative-pressure laser lithotripsy has any benefit over the conventional laser technique.

Conclusion

In our experience, our negative-pressure ureteroscopic lithotripsy is easy to learn and safe management for the ureteral stones. It might reduce the risk of stone fragment retropulsion, improve surgical vision, shorten operative time, and decrease the renal pelvic pressure; however, a comparative study with the conventional laser technique is required to confirm the result.

Statement of Ethics

The study was approved by the ethics committee of the hospital.

Disclosure Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Project development, data collection, and manuscript writing: Z.H.W., X.H.W., T.Z.L., and Y.Z.W. Manuscript editing: X.H.Z., Y.G.Z., and X.H.Z.

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