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RESEARCH

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Concomitant catheter drainage alleviates the thermal effect of holmium lasers during ureteroscopic lithotripsy: a retrospective cohort study

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Abstract

Background Thermal control is pivotal for preventing ureter thermal injury during laser lithotripsy; however, patient-based studies have rarely addressed this topic. In recent years, we have employed a ureter catheter for irrigation drainage and measured temperature changes during lithotripsy. The aim of this study was to evaluate the thermal control effect of this strategy in ureteroscopic holmium laser lithotripsy.

Methods From September 2022 to June 2024, patients who underwent ureteroscopic holmium laser lithotripsy at our centre were included in this retrospective cohort study. Patients were divided into a drainage group and a conventional group depending on whether a ureter catheter was used for concomitant drainage during lithotripsy. The temperature was measured using a K-type thermocouple thermometer. Lithotripsy was performed at an irrigation pressure setting of 30 mmHg and a laser setting of 1.0 J × 20 Hz. Intraoperative and follow-up data were compared between the groups.

Results Sixty-seven patients were included, including 32 in the drainage group and 35 in the conventional group. lgCEM$_{43}$ and the peak temperature of irrigation were significantly lower in the drainage group. The longest continuous lasing time was longer and the operation time was shorter than those in the drainage group. Compared with that in the conventional group, the quality of endoscopic vision in the drainage group during lithotripsy was significantly improved. There was no significant difference in the post-ureteroscopic lesion scale score or the 1-month stone-free rate between the groups. At the 6-month follow-up, no postoperative ureter stricture was observed in either group.

Conclusions The current thermal control strategy is safe and feasible; it significantly reduces the intraoperative irrigation temperature and improves endoscopic vision in ureteroscopic laser lithotripsy.

Keywords Drainage, Holmium laser, Lithotripsy, Temperature, Ureteroscopy

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Background

The holmium: yttrium-aluminum-garnet (Ho: YAG) laser is highly efficient for treating almost all stone compositions and is an ideal intracorporeal lithotripter for ureter stones [1]. Unlike pneumatic lithotripsy, which involves fragmenting stones directly via mechanical force, the Ho: YAG laser can fragment stones primarily via photothermal effects [2]. Therefore, the thermal effects of the Ho: YAG laser should not be underestimated, especially when high-power platforms are widely accessible.

The heat generated by lasers possibly leads to protein denaturation, gene damage and, ultimately, urothelial cell death [3]. A recent meta-analysis revealed a higher ureter stricture rate in the laser lithotripsy group than in the pneumatic lithotripsy group [4]. Although the cause of ureter stricture varies, thermal injury remains a non-negligible risk factor. A clinical study [5] evaluating the thermal effects of holmium laser lithotripsy under ureteroscopy revealed that the temperature of irrigation in all cases was greater than 43 °C, with 66.3% of irrigation temperatures exceeding 56 °C. Furthermore, three cases with an irrigation temperature > 56 °C progressed to hydronephrosis, indicating that irrigation overheating might contribute to ureter stricture.

Our previous clinical study addressed the importance of sufficient irrigation for preventing thermal injuries [6]. Nevertheless, it is difficult to maintain constant irrigation in semi-rigid ureteroscopy because of the lack of effective reflux. Therefore, we used a ureter catheter for intraoperative concomitant drainage. The aim of this study was to evaluate the thermal control effect of this strategy in ureteroscopic holmium laser lithotripsy.

Methods

Study design

This was a nonsynchronous controlled retrospective cohort study. Patients who underwent ureteroscopic Ho: YAG laser lithotripsy at our centre from September 2022 to June 2024 were retrospectively reviewed. They were divided into a drainage group and a conventional group according to whether a ureter catheter was used for irrigation drainage. The conventional group was patients treated prior to inclusion of the drainage strategy; and when high irrigation temperatures were noted during routine surgeries, our surgical team decided to switch to drainage strategy. The inclusion criteria were as follows: (1) patients were diagnosed with ureter stones, (2) surgeries were performed by the same endourology team, and (3) surgical videos and irrigation temperatures were recorded. Patients with congenital kidney/ureter malformations or ureter strictures were excluded.

Demographic data, as well as the stone side, location, maximum diameter, pre-stenting, stone-free rate (SFR) and postoperative ureter stricture, were obtained from medical records. Intraoperative data such as the operation time, maximum continuous lasing time (tmax), quality of endoscopic vision (QoEV) and the Post-Ureteroscopic Lesion Scale (PULS) scores [7] were retrieved by reviewing of surgery video files. QoEV and PULS scores were evaluated by two independent urologists. The peak temperature of irrigation (Tpeak) and cumulative equivalent minutes at 43 °C (CEM_{43}) were calculated on the basis of the temperature profiles recorded by the thermometer.

Sample calculation

According to the aim of this study, $lgCEM_{43}$ was considered the primary outcome measure. A continuous bilateral test was used; the α level was 0.05, and the test power (1 – β) was 0.9. On the basis of our previous results, the mean $lgCEM_{43}$ values were – 2.03 ± 3.67 and 1.25 ± 3.21 in the drainage and conventional groups, respectively. PASS 15 software (NCSS, Kaysville, Utah, USA) was used to calculate the required sample size. The required sample size was determined to be 28 cases. After accounting for a potential dropout rate of 10%, the minimum sample size was 31 cases in each group.

Surgical procedures

After general anaesthesia, the patient was placed in the lithotomy position. Ureteroscopy was performed using an 8/9.8 F semi-rigid ureteroscope (Wolf, Knittlingen, Germany) prior to lithotripsy.

Concomitant catheter drainage group (Drainage group)

After ureteroscopy, a 5 F ureter catheter (Cook, Bloomington, IN, USA) was inserted into the ureter over the stone through a nitinol core wire guide (Cook, Bloomington, IN, USA). The ureteroscope was reinserted into the ureter alongside the catheter (Fig. 1). The position of the catheter was adjusted (usually pulled back to avoid folding in the renal pelvis) to obtain constant irrigation outflow. Then, a laser fibre with a K-type thermocouple was inserted, and lithotripsy began. After lithotripsy, the stone fragments were removed using a basket (Cook, Bloomington, IN, USA), and a double-J stent (Cook, Bloomington, IN, USA) was placed.

Conventional lithotripsy group (Conventional group)

No ureter catheter was placed, and the other surgical procedures were the same as those in the ureter catheter drainage group.

Irrigation and laser settings

Saline irrigation was maintained at room temperature (24 °C) and delivered to the ureteroscope by a YDJ-111 peristaltic pump (Yida, Hangzhou, Zhejiang, China) at a pressure setting of 30 mmHg. Lithotripsy was performed

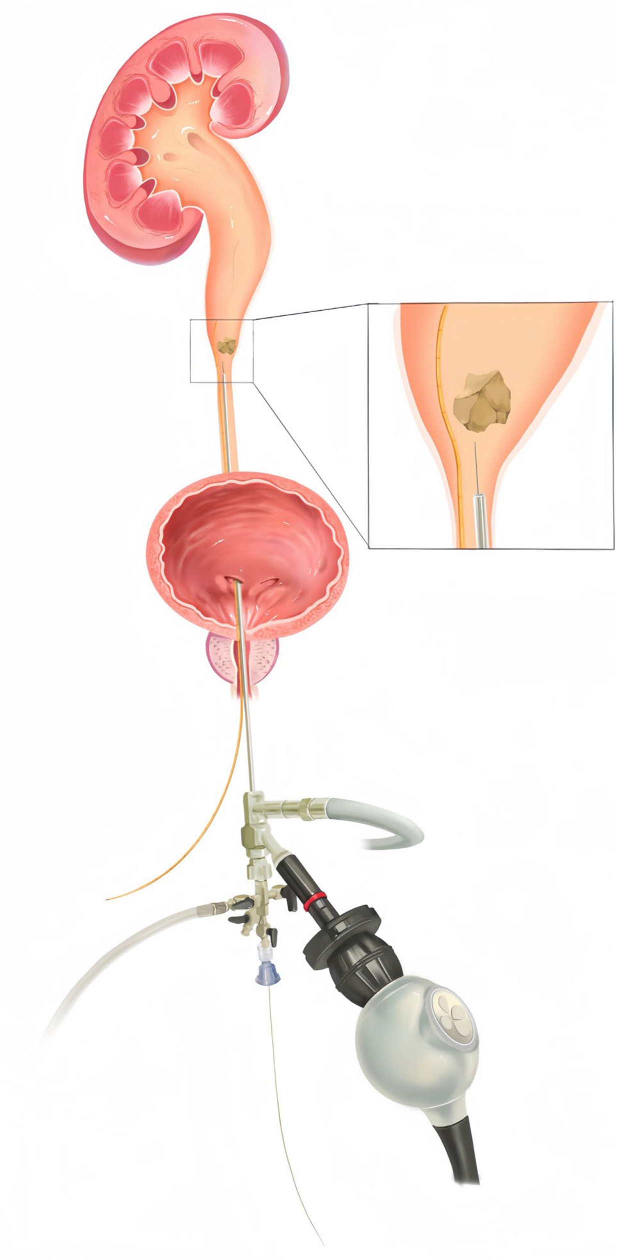

Fig. 1 Schematic diagram of concomitant ureteral drainage during lithotripsy Laser lithotripsy was performed with a 5 F catheter alongside the ureteroscope. The tip of the catheter was placed over the stone to obtain constant irrigation outflow and avoid fragment obstruction

via a Lumenis PULSE 120 H system (Lumenis, Yokneam, Israel) in short pulse mode at 1.0 J × 20 Hz.

Temperature measurements

The irrigation temperatures were measured with an OMEGA® RDXL4SD thermometer (Engineering Inc., Taiwan) with a KPS-QB-K-1000-SMPW K-type thermocouple (Suma, Taizhou, Zhejiang, China) fixed to a 200-μm laser fibre (Lumenis, Yokneam, Israel) using a surgical film (Renhe, Hanzhou, Zhejiang, China) (Fig. 2). Temperature changes were automatically recorded by a thermometer every second from the time of activation of the laser until the end of lithotripsy.

Postoperative follow-up

The double-J stent was removed at 2–4 weeks after the operation. Abdominal–pelvic computed tomography (CT) was performed 1 month and 6 months after the operation to evaluate stone clearance and ureter stricture.

Definitions

Stone-free status was defined as no detectable stones or stone fragments ≤ 3 mm on CT. The operation time referred to the duration of lithotripsy from the beginning of the first pedal activation to the end of the last pedal activation. t_{max} was defined as the longest lasing time for one pedal activation. The QoEV reflects the clarity of the surgical field during laser activation. It was scored using a self-developed 5-point rating scale, where a higher score represented better clarity (Fig. 3). CEM_{43} was used to evaluate the thermal dose and was calculated using the following formula: $CEM_{43} = \Sigma \Delta t \cdot R^{(43-T)}$ ($R = 0.5$ for $T > 43$ °C, $R = 0.25$ for $T < 43$ °C) [8].

Statistical analysis

Normality and homoscedasticity were verified by the Shapiro–Wilk test and Levene's test, respectively. Continuous variables with a normal distribution are presented as the mean ± standard deviation (SD) or mean ± standard error (SE); continuous variables with a nonnormal distribution are presented as the median (interquartile range, IQR). Student's t test was used for continuous variables with a normal distribution and homoscedasticity, the Welch test was used for continuous variables with a normal distribution but heteroscedasticity, and the Mann–Whitney U test was used for continuous variables with a nonnormal distribution. Categorical variables were compared using Fisher's exact test. All the statistical analyses were performed using IBM SPSS Statistics version 20 (IBM SPSS Inc.). $P < 0.05$ was considered statistically significant.

Results

Sixty-seven patients were included into our retrospective study, including 32 in the drainage group and 35 in the conventional group. In the drainage group, 5 patients were pre-stented. Three of these patients were pre-stented due to ureteral tract infection, while 2 were pre-stented due to failure of ureteroscopy at the first attempt. In the conventional group, 3 patients were pre-stented due to failed ureteroscopy at the first attempt, and 2 patients were converted from the planned drainage group. No significant difference was found in terms

Fig. 2 Temperature measurement during lithotripsy The K-type thermocouple was fixed to a 200-µm laser fibre using a surgical film. The temperature was measured every second by a thermometer

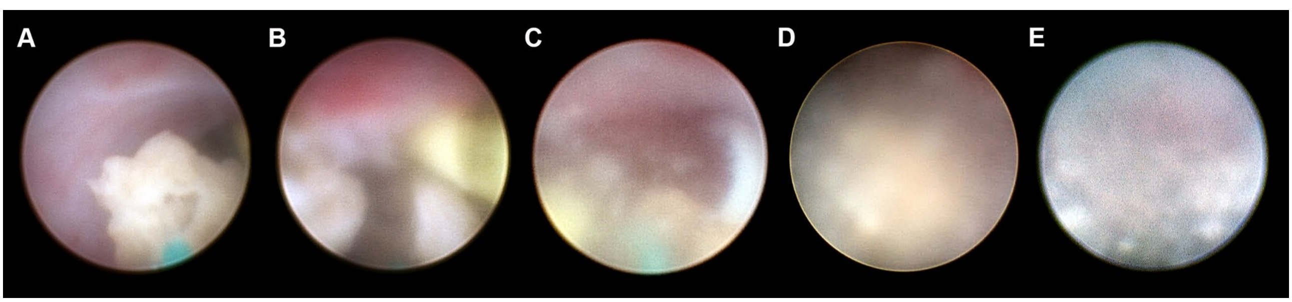

Fig. 3 Ureteroscopic view of different QoEV scores **A** Ureteroscopic view with a score of 5. Clear endoscopic vision with a tiny amount of stone dust, which has no influence on lithotripsy. **B** Ureteroscopic view with a score of 4. Relatively clear endoscopic vision with a small amount of stone dust has almost no influence on lithotripsy. **C** Ureteroscopic view with a score of 3. Endoscopic vision between a score of 2 and 3, with recognizable adjacent structures, has a slight influence on lithotripsy. **D** Ureteroscopic image with a score of 2. Blurred endoscopic vision with a moderate amount of stone dust but becomes clear quickly; lithotripsy is interrupted for a short period of time. **E** Ureteroscopic view with a score of 1. When there is blurred endoscopic vision with a large amount of stone dust, manual drainage is needed, and lithotripsy is interrupted for a long period of time QoEV, quality of endoscopic view

of demographic or clinical features between the groups (Table 1).

Intergroup comparisons revealed considerable advantages in favour of the drainage group (Table 1; Fig. 4). The CEM_{43} was significantly shorter in the drainage group (0.00044 (0.22 min) vs. 76.49 (3646.25), $P<0.001$). Since the CEM_{43} data were nonnormally distributed, considering the calculation method of CEM_{43}, we took the logarithm of CEM_{43} and reperformed the comparison. The results revealed that $lgCEM_{43}$ was significantly lower in the drainage group (-3.20 ± 2.72 vs. 2.02 ± 2.95, $P<0.001$). In the drainage group, the mean peak temperature of irrigation was 39.95 °C, which was much lower than that in the conventional group (39.34 ± 5.88 vs. 54.28 ± 9.11, $P<0.001$). Additionally, 34.28% (12/35) of the patients in the conventional group exceeded the T_{peak} of 56 °C, whereas none of the patients in the drainage group exceeded the T_{peak}.

The clarity of the surgical field evaluated by the QoEV was much better in the drainage group (3.50 (0.88) vs. 1.50 (0.50), $P<0.001$). Consequently, the longest continuous lasing time (11.50 (4.00) vs. 3.00 (2.00), $P<0.001$) was longer, and the operation time (7.15 ± 3.47 vs. 14.93 ± 7.66, $P<0.01$) was shorter than that of the drainage group. No significant difference in PULS was noted between the groups.

At the 1-month follow-up, the SFRs were similar between the groups. At the 6-month follow-up, no patients in either group developed ureter stricture.

Discussion

Concerns about the thermal effects of laser lithotripsy are increasing. In 2015, Molina WR carried out the first laser lithotripsy thermography study [9]. In their study, laser lithotripsy was performed on an intact urinary tract with a power setting of 10 W, and the data revealed that

Table 1 Comparisons of variables between drainage group and conventional group

	Drainage Group (*N* = 32)	Conventional Group (*N* = 35)	*P*
Demographic & clinical features			
Gender			1.000
Male	18	20	
Female	14	15	
Age	52.56 ± 12.09	53.00 ± 12.85	0.887
BMI	26.14 ± 3.49	25.34 ± 3.20	0.333
Stone Side			0.628
Left	17	16	
Right	15	19	
Stone Location			1.000
Abdominal part	17	19	
Pelvic part	15	16	
Maximum Stone Diameter (cm)	1.40 ± 0.39	1.57 ± 0.50	0.146
Pre-stenting	5	3	0.464
Intra-operative Data			
CEM_{43} (min)	0.00044 (0.22)	76.49 (3646.25)	< 0.001
$lgCEM_{43}$	-3.20 ± 2.72	2.02 ± 2.95	< 0.001
T_{peak} (°C)	39.34 ± 5.88	54.28 ± 9.11	< 0.001
QoEV	3.50 (0.88)	1.50 (0.50)	< 0.001
t_{max} (s)	11.50 (4.00)	3.00 (2.00)	< 0.001
Operation Time (min)	7.15 ± 3.47	14.93 ± 7.66	< 0.001
PULS			0.594
Grade 0	21	26	
Grade 1	11	9	
Grade 2+	0	0	
Follow-up			
SFR	90.63% (29/32)	85.71% (30/35)	0.711
Ureter Stricture	0	0	/

BMI, body mass index. CEM_{43}, cumulative equivalent minutes at 43 °C. T_{peak}, the peak temperature of Irrigation fluid. t_{max}, maximum continuous lasing time. QoEV, quality of endoscopic vision. PULS, post-ureteroscopic lesion scale. SFR, stone-free rate

the external ureteral wall reached temperatures of 37.4 °C and 49.5 °C with and without irrigation, respectively. Subsequent studies evaluating the temperature profiles of irrigation during ureteroscopic Ho: YAG laser lithotripsy using different models demonstrated that sufficient irrigation is beneficial for intraoperative temperature control [10–16].

Theoretically, temperature changes can be calculated through the formula $Q = cm\varDelta T$ (Q, energy absorbed by irrigation; c, specific heat capacity of irrigation; m, mass of the irrigation, $\varDelta T$, temperature change). Under ideal conditions, regardless of thermal diffusion, the formula can be transformed to $\varDelta T = \frac{Q}{c \cdot m} = \frac{W \cdot t}{c \cdot \rho \cdot v \cdot t} = \frac{W}{c \cdot \rho \cdot v}$ (W, laser power; ρ, density of irrigation; v, irrigation flow; t, laser activation duration). As c and ρ are constants, the temperature change is directly proportional to the laser power and inversely proportional to the irrigation flow.

Increasing irrigation flow seems reasonable for avoiding thermal injury. However, in clinical practice, although the setting value of the peristaltic pump has increased, the actual flow cannot be greatly improved because of the narrow space of the ureter. Additionally, the intrarenal pressure (IRP) should be taken into consideration to reduce pyelovenous backflow and complications [17]. Therefore, we developed a strategy to increase irrigation by maintaining constant drainage. We also attempted to place the catheter below the stone; however, drainage was frequently interrupted by fragment obstruction.

In the present study, pre-stenting was not routinely performed unless acute obstructive renal insufficiency or pyenephrosis was suspected. Among the 59 non-stented patients, 29 were planned for catheter drainage; however, 2 eventually received conventional treatment because of failed ureteroscopy with concomitant catheter drainage. The overall success rate of our drainage procedure at the first attempt was 93.1% (27/29), similar to the reported success rate of initial ureteroscopy (88.5%) [18]. Additionally, our data revealed a similar PULS between the groups. Overall, we believe that it is unnecessary to routinely pre-stent.

The use of ureter catheters in ureteroscopic lithotripsy was first reported by Wu ZH [19]. In their study, a modified 5 F ureter catheter with a laser fibre inside was used for lithotropsy. Yi X [20] developed a new stone occlusion device using a 5 F ureter catheter with its end split into 4 strips. In both studies, negative pressure was applied to facilitate drainage. Zhu X [16] employed a method similar to that of Wu ZH but without negative pressure and measured the temperature changes during irrigation when laser firing stopped in a model; however, the temperature changes during laser firing were not assessed. In fact, the peak temperature of the drainage group was over 56 °C (2.0 J×10 Hz and 1.5 J×20 Hz, 15 ml/min, laser firing times of 5 s and 10 s), which could cause thermal injuries in 1 s [5].

A common point of the above three studies was that the catheter was inserted through the working channel of the ureteroscope to the ureter. The 8/9.8 F ureteroscope allows the 5 F device to pass through, leaving very limited space for irrigation. When a 200-μm laser fibre or a steel wire is placed in the catheter, approximately 20% of its lumen is occupied. These factors inevitably interfere with irrigation and drainage flow. We overcame these shortcomings by placing the catheter outside the ureteroscope. Our study showed satisfying results in terms of temperature reduction, with a T_{peak} of 39.95 °C in the drainage group vs. 54.42 °C in the conventional group. Moreover, endoscopic visualization was significantly better in the drainage group than in the drainage group

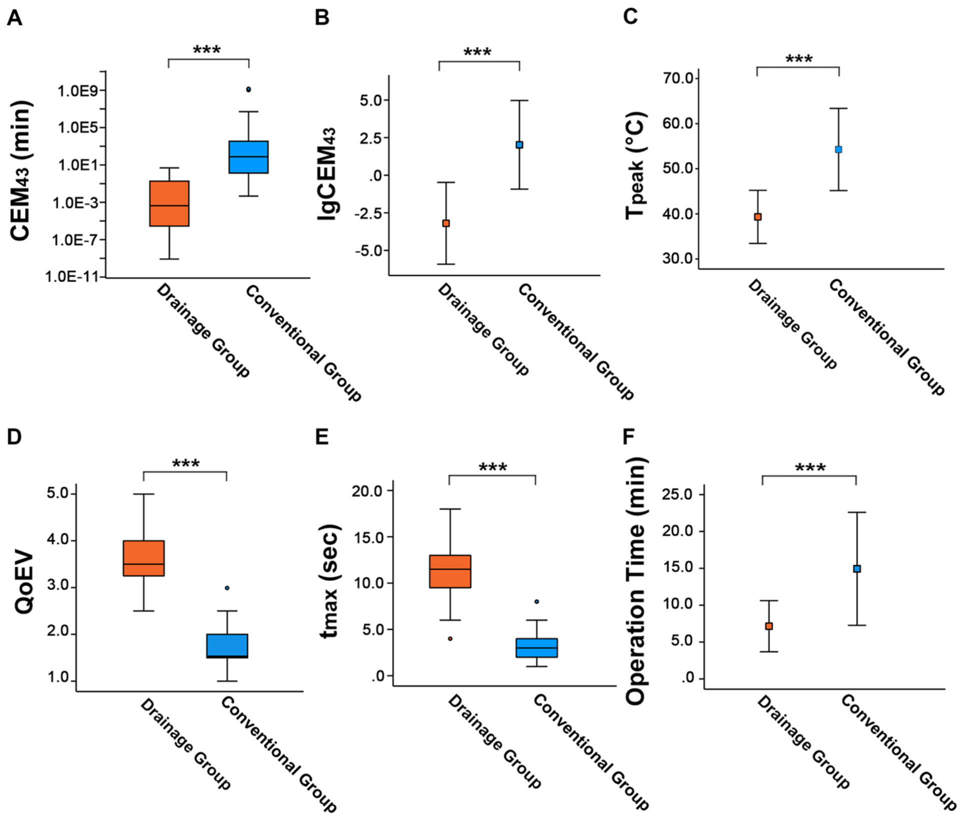

Fig. 4 Comparisons of intra- and postoperative parameters between groups **A** CEM_{43} was significantly shorter in the drainage group. **B** $lgCEM_{43}$ was significantly lower in the drainage group. **C** The peak temperature of irrigation during lithotripsy was significantly lower in the drainage group. **D** The clarity of ureteroscopic vision during lithotripsy was significantly better in the drainage group. **E** The longest lasing time was significantly longer in the drainage group. **F** The operation time was significantly shorter in the drainage group ***, $P < 0.001$ CEM_{43}, cumulative equivalent minutes at 43 °C. T_{peak}, the peak temperature of Irrigation. t_{max}, maximum continuous lasing time. QoEV, quality of endoscopic vision. PULS, post-ureteroscopic lesion scale

because of sufficient drainage and irrigation (Supplementary Video 1).

Unlike in vitro studies, irrigation is difficult to stabilize at a certain flow rate in clinical practice. To maintain a clear endoscopic view or to reduce stone migration during lithotripsy, water valves are frequently adjusted to control irrigation and drainage. Therefore, we aimed to enrol patients whose surgeries were performed by the same endourology team. In this context, identical peristaltic pump settings and similar surgeon preferences during lithotripsy might help minimize bias.

He Z [21] measured the IRP via a drainage method similar to that used by Zhu X in an artificial model, and the data revealed that the IRP was significantly lower and that no intrarenal hypertension was observed in the drainage group. Unfortunately, since percutaneous renal puncture is needed to deliver a pressure-measuring catheter into the renal pelvis, which might cause additional injuries to patients, IRP changes were not monitored in our study.

The cumulative equivalent minutes (CEMs) were established by Sapareto and Dewey [8] to assess the thermal dose at different thermal exposures; they reported that a "break" temperature of 43 °C was arbitrarily chosen as the best estimate from all available data. Although $CEM_{43} = 120$ min is widely used as a threshold of tissue damage, it is important to note that the thermal response differs between tissues and species. For example, animal experiments have shown that $CEM_{43} > 80$ min leads to significant bladder damage, whereas $CEM_{43} > 70$ min causes significant kidney damage [22]. Unfortunately, the threshold thermal dose for the human ureter is not well defined in the published literature. In our study, several patients whose CEM_{43} exceeded 120 min were included; however, no stricture was found. Future studies are needed to further determine the specific thermal dose for the ureter and urothelial tissues to increase our understanding of thermal damage thresholds in laser lithotripsy.

Some limitations exist in the present study. First, although favourable conclusions were drawn, the study population was small. Large-scale prospective clinical trials are needed to further validate the efficacy and safety of this drainage strategy. Second, we evaluated the temperature changes at only one laser power and irrigation pressure setting. More settings are needed in future studies to explore safe power and irrigation pressure ranges under the current drainage strategy. Third, we used only the ureteral stricture as a surrogate marker for thermal damage, but no such complications occurred; therefore, long-term follow-up, as well as other thermal injury markers, such as inflammatory cytokines and fibrosis-related markers, are needed to further address this issue. Fourth, we did not use safety guide in conventional group due to economic reason and surgeon's personal habit, although it might provide some benefits for drainage to both the bladder and the upper urinary system. We would assess the thermal control effects of safety guide in future studies.

Conclusions

Concomitant catheter drainage could significantly reduce the irrigation temperature and improve endoscopic vision during ureteroscopic laser lithotripsy. Moreover, the procedure caused no additional injury to the ureter. This thermal control strategy is safe and feasible and would be beneficial not only during laser lithotripsy but also during other ureteroscopic procedures.

Abbreviations

Ho:YAG	Holmium: yttrium-aluminum-garnet
BMI	Body mass index
CT	Computed tomography
QoEV	Quality of endoscopic vision
PULS	Post-ureteroscopic lesion scale
CEM_{43}	Cumulative equivalent minutes at 43 °C
SD	Standard deviation
SE	Standard error
IQR	Inter-quartile range
IRP	Intra-renal pressure

Supplementary Information

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Supplementary Material 1

Author contributions

Study concept and design: J.T. Data acquisition: X.A., C.M., X.L., Y.G., L.Y. Data analysis: C.M., X.A., J.T., K.W. Drafting of manuscript: X.A., C.M. Critical revision of the manuscript: J.T.

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Data availability

The datasets generated and/or analysed during the current study are not publicly available due to patients' privacy but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study protocol has been approved by Institutional Review Board of the Seventh Medical Centre of PLA General Hospital (No. 2023151) and it conforms to the provisions of the Declaration of Helsinki. Informed consent to participate was obtained from the participants whose intra-operative video or picture were used in the study, otherwise, the need for consent to participate was waived by IRB of the Seventh Medical Centre of PLA General Hospital.

Consent for publication

Consents for publication were obtained from the participants whose intra-operative video or picture were used in the study.

Competing interests

The authors declare no competing interests.

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