

Original Article

Intrarenal thermal and pressure dynamics during ureteroscopy: an *in vitro* study

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Objectives

To evaluate *in vitro* determinants of intrarenal temperature (IRT) and pressure (IRP) during laser lithotripsy.

Materials and Methods

A **silicone urinary tract model** was used to perform **laser lithotripsy on artificial stones** placed in the renal pelvis. Three laser sources (thulium fibre laser, holmium:yttrium-aluminium-garnet [Ho:YAG] with Magneto Technology, and pulsed thulium:YAG) with 200-µm fibres were tested at four energy settings (0.6 J–10 Hz, 1 J–10 Hz, 0.2 J–50 Hz, and 1 J–40 Hz), delivering 2000 J per experiment. Irrigation was **provided by gravity (40 cmH₂O)** or hand-pump irrigation, combined with a standard ureteral access sheath (sUAS) or flexible and navigable suction sheath (FANS). Multivariable regression identified predictors of mean IRT and IRP.

Results

Baseline temperatures were comparable among groups (27.2–32.2 °C, $P > 0.05$). **Hand-pump irrigation reduced mean IRT compared to gravity (−9.1 °C, $P = 0.001$).** **Laser power showed a dose–response effect (10 W: +2.5 °C, $P = 0.003$; 40 W: +8.2 °C, $P = 0.001$ vs 6 W).** At equivalent power and irrigation settings, laser source did not influence IRT under the experimental conditions evaluated. The **thermal-risk threshold (>43 °C) was reached in 16.7% of experiments**, increased with power (2.8%, 15.3%, and 41.7% at 6, 10, and 40 W; $P = 0.001$) and decreased with hand-pump irrigation and FANS ($P < 0.05$). **Hand-pump irrigation increased IRP by 21 cmH₂O compared to gravity, while FANS reduced IRP by 12 cmH₂O vs sUAS ($P = 0.001$).**

Conclusions

Mean IRT was associated with laser power and irrigation strategy. High-power settings (40 W) frequently exceeded the thermal-risk threshold. Although FANS was not associated with lower mean IRT, it reduced the likelihood of exceeding the thermal-risk threshold. Laser source had no effect on mean IRT when power and irrigation conditions were comparable. Mean IRP was influenced by irrigation strategy and UAS configuration but was not associated with mean IRT. These findings underscore the need for **advanced integrated irrigation–aspiration systems capable of dynamic control of flow, pressure, and temperature to optimise procedural safety.**

Keywords

pressure, temperature, ureteroscopy, endourology, FANS

Introduction

Despite major innovations in endourology, the optimal balance between irrigation efficiency, aspiration, and procedural safety remains unclear [1–4].

Laser lithotripsy is the standard treatment for upper urinary tract stones; however, thermal injury remains a potential complication, especially since the advent of high-power lasers. Experimental studies have shown that intrarenal temperatures (IRTs) may exceed thresholds associated with protein denaturation ($>43^{\circ}\text{C}$), especially when laser power is applied under low-flow irrigation conditions [5–7].

Irrigation and outflow conditions are believed to influence IRT through their effects on heat removal, while ureteric access sheaths (UAS) play an important role in intrarenal pressure (IRP) and irrigation dynamics [8]. Flexible and navigable suction sheaths (FANS) and intelligent aspiration-irrigation systems have been introduced to actively evacuate irrigation and stone fragments while trying to maintain a controlled pressure balance, potentially improving both visualisation and safety [9,10].

While the relationship between IRP and urosepsis is well established, its interaction with intrarenal thermal dynamics remains unclear [11]. Prior studies have evaluated temperature at a single intrarenal location, and limited data exist regarding spatial temperature gradients within the collecting system or the dynamic effect of aspiration on temperature and pressure profiles.

Available data on IRT have largely been derived from studies using the holmium:yttrium-aluminium-garnet (Ho:YAG) laser and, more recently, the thulium fibre laser (TFL) [12–14]. Comparative information regarding newer laser sources, such as the pulsed thulium:YAG (p-Tm:YAG) laser, remains scarce, particularly regarding their association with IRT and IRP.

We aimed to evaluate the determinants of IRT and IRP during laser lithotripsy and to assess the associations of laser power, laser source, irrigation strategy, and UAS configuration—including an aspiration-based system—with mean IRP and IRT under controlled experimental conditions.

Materials and Methods

Experimental Setup

A male urinary tract silicone model (ETXY-URO Simulator, Pro Delphus, Olinda, Pernambuco, Brazil) was used for the experiments (Fig. 1a,d). BegoStones (Bego®, Bremen, Germany) phantoms (15:3 ‘powder-to-water’ ratio) were introduced through an orifice in the lower renal pole and

positioned in the renal pelvis. The system was then secured with 5-0 polypropylene sutures to prevent leakage.

Three laser sources were compared: 60 W TFL Drive (TFL, Coloplast®, Amersfoort, The Netherlands), 150 W Ho:YAG (Magneto, Cyber Ho-Magneto, Quanta Systems®, Samarate, Italy), and 100 W p-Tm:YAG (Thulio, Dornier MedTech®, Weßling-Oberpfaffenhofen, Germany) with single-use 200- μm laser fibres, cleaved between each experiment. Four energy settings were defined (0.6 J–10 Hz, 1 J–10 Hz, 0.2 J–50 Hz, and 1 J–40 Hz), delivering 2000 J per experiment. The TFL, p-Tm:YAG and Ho:YAG were set to ‘Short Pulse’ (peak power: 500 W), ‘Flex Long Pulse’ (peak power: 560–2200 W), and ‘Magneto’ (peak power: 600 W) modes, respectively. Due to generator limitations, the p-Tm:YAG could not be tested at 1 J–40 Hz. Regarding Ho:YAG Magneto platform restrictions, 0.8 J–40 Hz (32 W) was selected (instead of 1 J–40 Hz).

Irrigation was performed using 0.9% saline solution at room temperature. Irrigation methods included gravity flow at 40 cmH_2O and hand-pump irrigation (TFlow™ Dual Port–Gravity Line, Rocamed®, Monaco), with gradual pump compression every 10 s followed by a 10-s release period to standardise irrigation delivery across experiments. Two UAS were evaluated: the 10/12-F ReTrace® UAS (Coloplast) standard ureteral access sheath (sUAS) and the 10/12-F ClearPetra® FANS (Well Lead®, Panyu, Guangzhou, China), the latter connected to -100 mmHg suction and intermittently switched between open and closed vent modes every 20 s.

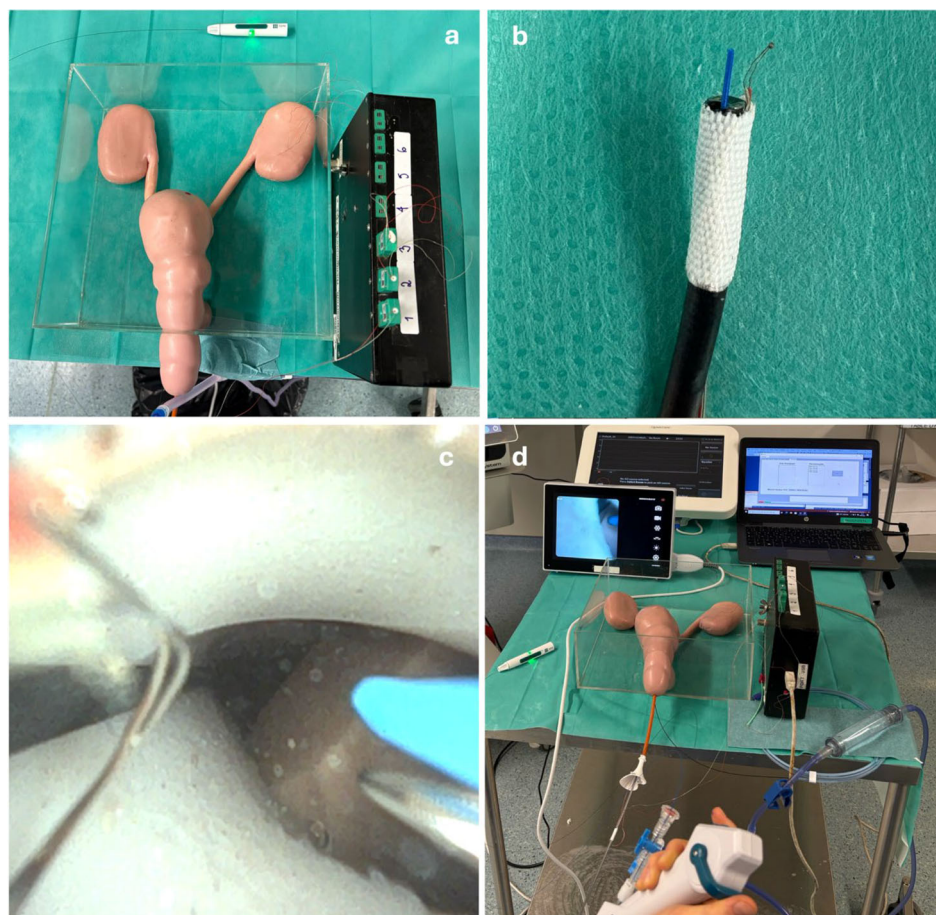
All experiments were conducted using a 7.5-F digital ureteroscope (Pusen Medical Technology Co., Zhuhai, Guangdong, China) and were performed by the same three operators to ensure procedural consistency.

The IRP and IRT were continuously recorded in the renal pelvis; temperature was also recorded in the lower and upper calyces throughout each experiment. Each experiment was repeated three times; because p-Tm:YAG could not be tested at 1 J–40 Hz, the four corresponding experimental settings were performed only with TFL and Ho:YAG Magneto, resulting in a total of 132 procedures.

For IRP recording, the 356 μm (0.014” or 1.1 F) PressureWire™ guidewire (St. Jude Medical®, St. Paul, MN, USA) connected to a monitor (QUANTIEN™ system) was used [15,16].

For IRT recording, two K-type 76 μm (0.003” or 0.23 F) thermocouple wires were introduced in the upper and lower calyx with the use of an 18G needle; the temperature recording in the renal pelvis was introduced retrogradely alongside the ureterscope with a third K-type thermocouple wire, with the sensor at the tip of the ureterscope, in close proximity to the laser fibre (Fig. 1b,c).

Fig. 1 (a) Top-down view of the experimental setup using a silicone male urinary tract model placed inside a transparent acrylic container. IRT sensors are externally connected to a multichannel recording system positioned adjacent to the model. (b) Close-up view of the ureterscope tip showing the laser fibre and thermocouple wire positioned at the distal end. (c) Endoscopic image obtained during laser lithotripsy within the collecting system. The laser fibre tip and IRT sensor are visible in close proximity to the stone phantom; the IRP sensor is positioned near the renal pelvis and outside the UAS. (d) Global view of the complete experimental setup, including the silicone urinary tract model, flexible ureterscope, irrigation system and UAS, IRP and IRT monitoring devices, and data acquisition consoles.



Statistical Analyses

Continuous variables were reported as mean (SD) and categorical variables as frequencies and percentages. To identify predictors of mean IRT, a multivariable linear regression model was fitted. Mean IRT in this model was defined as the average temperature recorded at the three intrarenal sensor locations throughout the experiment, including both laser activation and aspiration phases. Laser source was included as a three-level categorical variable (TFL, Ho:YAG Magneto, p-Tm:YAG), and laser power was included as a categorical variable (6, 10, and 32–40 W). Irrigation method (gravity vs hand-pump irrigation) and UAS (sUAS vs FANS) were included as binary variables; mean IRP was included as a continuous covariate (Model 1).

A second multivariable logistic regression model was constructed to identify predictors of thermal risk, defined as a

mean IRT exceeding the predefined 43 °C threshold (Model 2). The dependent variable was thermal risk (yes/no) and independent variables the same as Model 1. Odds ratios (ORs) with 95% CIs were calculated.

A third linear multivariable regression model similar to Model 1 was constructed, using mean IRP as the dependent variable (Model 3).

Given the strong correlation between laser power parameters (watts, setting, energy and frequency), only laser power (watts) was retained in the multivariable model to avoid multicollinearity.

In addition to regression analyses, Pearson's correlation coefficient was calculated to assess the linear association between mean IRP and mean IRT. This exploratory analysis was intended to characterise the direction and strength of the association between mean IRP and IRT under different

irrigation and access system conditions, without implying a causal relationship.

A two-sided $P < 0.05$ was considered statistically significant. Statistical analyses were performed using the IBM SPSS® Statistics version 25.0 (IBM Corp., Armonk, NY, USA).

Results

General Descriptive Results

Mean baseline temperatures were comparable among the different experimental settings (27.2–32.2 °C, $P > 0.05$). Table S1 summarises pooled temperature data for each experimental condition, irrespective of laser source. Within these combined data, the lowest mean IRT was observed with hand-pump irrigation, sUAS, and 0.6 J–10 Hz in the lower calyx (29.4 °C), whereas the highest mean IRT was observed with gravity irrigation, FANS, and 1 J–40 Hz in the renal pelvis (53.7 °C), with peak temperatures reaching 76.3 °C.

The IRT was consistently higher in the renal pelvis (37.4 °C)—closest to the laser fibre tip—than in the lower and upper calyces (34.2 °C and 32.5 °C, $P = 0.001$). Experiments combining gravity irrigation and high laser power showed the highest mean and peak IRT, whereas hand-pump irrigation and FANS showed lower temperatures across all settings.

The IRP varied markedly according to irrigation modality and access system. The highest values were observed with hand-pump irrigation combined with a sUAS (mean [SD] 25.0 [8.7] cmH₂O), while the lowest pressures occurred with gravity irrigation and FANS (mean [SD] −2.4 [2.6] cmH₂O). Gravity irrigation with sUAS (mean [SD] 6.8 [2.5] cmH₂O) and hand-pump irrigation with FANS (mean [SD] 10.1 [2.1] cmH₂O) showed intermediate levels (Table S2).

Regression Models

Model 1: Mean IRT (°C)

Mean IRT was primarily associated with irrigation method and laser power (Table 1). Compared with gravity irrigation, hand-pump irrigation was associated with significantly lower IRT (−9.12 °C, 95% CI −11.22 to −7.02; $P = 0.001$). Laser power showed a strong dose–response effect on mean IRT: compared with 6 W, 10 W increased temperature by 2.5 °C ($P = 0.003$) and 32–40 W increased temperature by 8.22 °C ($P = 0.001$). Neither mean IRP nor the use of FANS predicted mean IRT.

Although p-Tm:YAG was associated with a slightly higher mean IRT than TFL in the multivariable model (+1.97 °C, 95% CI 0.09–3.84; $P = 0.040$), no significant differences were observed between laser sources when temperatures were compared within equivalent power settings. Mean IRT did

Table 1 Multivariable linear regression model identifying determinants of mean IRT.

Variable	B (°C)	95% CI	P
Irrigation (gravity vs hand-pump)	−9.12	−11.22 to −7.02	<0.001
UAS (sUAS vs FANS)	−1.06	−2.91 to 0.79	0.26
Laser source			
Magneto vs TFL	+0.55	−1.13 to 2.22	0.52
p-Tm:YAG vs TFL	+1.97	0.09 to 3.84	0.04
Laser power (watts)			
10 W vs 6 W	+2.50	0.86 to 4.14	0.003
32–40 W vs 6 W	+8.22	5.34 to 11.10	<0.001
Mean IRP (cmH ₂ O)	+0.02	−0.08 to 0.12	0.73

Reference categories: TFL (laser), gravity irrigation, sUAS, 6 W. Model fit: $R^2 = 0.65$.

not differ significantly between TFL, Ho:YAG Magneto, and p-Tm:YAG at 6 W (34.3 °C, 32.4 °C, and 35.3 °C, respectively; $P = 0.30$) or 10 W (35.8 °C, 36.2 °C, and 37.5 °C, respectively; $P = 0.55$). At 32–40 W, mean IRT was also similar between TFL and Ho:YAG Magneto (41.7 °C and 42.1 °C, respectively; $P = 0.91$). It should be noted that p-Tm:YAG was not tested at 40 W and that Ho:YAG Magneto reached a maximum power of 32 W because of platform limitations.

Model 2: Thermal Risk (Mean Temperature >43 °C)

Using a predefined thermal-risk threshold of 43 °C, 16.7% of experiments exceeded this threshold. The proportion of experiments above this threshold was markedly higher with gravity irrigation compared with hand-pump irrigation (30.3% vs 3%, $P = 0.001$). Thermal risk was lower with FANS vs sUAS (9.1% vs 24.2%, $P = 0.03$). The proportion of experiments exceeding the thermal-risk threshold increased stepwise with power, from 2.8% at 6 W to 15.3% at 10 W and 41.7% at 40 W ($P = 0.001$).

In this multivariable logistic regression analysis, irrigation method, UAS type, and laser power were predictors of thermal risk. Hand-pump irrigation was associated with a marked reduction in the odds of exceeding the thermal-risk threshold compared with gravity irrigation (OR 0.02, 95% CI 0.001–0.41; $P = 0.011$), and the use of FANS was also protective (OR 0.08, 95% CI 0.009–0.77; $P = 0.029$). Laser power showed a strong dose–response relationship, with 40 W markedly increasing the odds of thermal risk compared with 6 W (OR 304.7, 95% CI 7.0–13 264; $P = 0.002$). In contrast, laser source and mean IRP were not associated with thermal risk (Table 2).

Model 3: Mean IRP (cmH₂O)

Mean IRP was associated with irrigation strategy and UAS. Hand-pump irrigation increased IRP by ~21 cmH₂O

Table 2 Multivariable logistic regression for predictors of thermal risk (mean temperature >43 °C).

Variable	OR	95% CI	P
Irrigation (gravity vs hand-pump)	0.02	0.001–0.41	0.011
UAS (sUAS vs FANS)	0.08	0.009–0.77	0.029
Laser source			
Magnetot vs TFL	1.29	0.14–11.95	0.83
p-Tm:YAG vs TFL	4.86	0.68–34.90	0.12
Laser power (watts)			
10 W vs 6 W	8.94	0.89–90.10	0.063
32–40 W vs 6 W	304.70	7.00–13 264	0.002
Mean IRP (cmH ₂ O)	0.94	0.79–1.13	0.51
Reference categories: TFL (laser), gravity irrigation, standard UAS, 6 W. Pseudo R ² = 0.48.			

compared with gravity irrigation (95% CI 18.3–24.5, $P = 0.001$), whereas the use of FANS reduced IRP by ~12 cmH₂O (95% CI –14.5 to –9.4, $P = 0.001$). Laser source, laser power and mean IRT were not associated with IRP (Table 3).

Correlation Between IRT and IRP

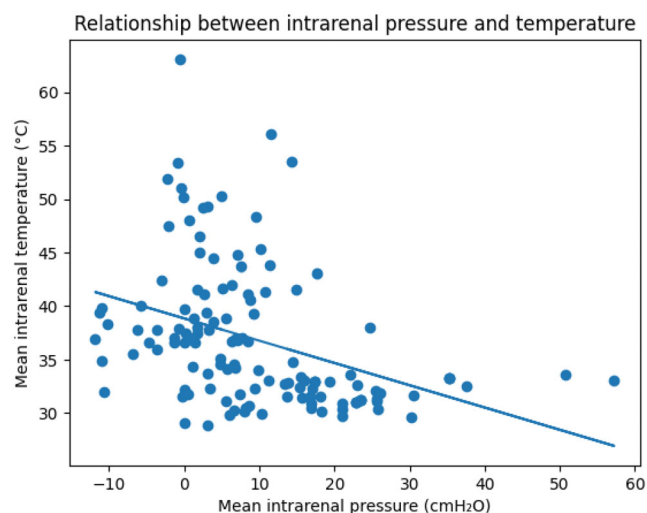
A significant inverse correlation was observed between mean IRT and mean IRP ($r = -0.385$, $P = 0.001$). This relationship may reflect differences in irrigation dynamics; however, irrigation flow was not directly measured in the present study (Fig. 2).

Discussion

In this controlled experimental study, we demonstrated that laser power and irrigation strategy were the primary determinants of mean IRT during laser lithotripsy. Because irrigation modality, UAS configuration, and IRP represent interconnected components of intrarenal fluid dynamics, these findings should be interpreted as associations observed within this experimental model rather than as evidence of

Table 3 Multivariable linear regression model identifying predictors of mean IRP (cmH₂O).

Variable	B (cmH ₂ O)	95% CI	P
Irrigation (gravity vs hand-pump)	+21.4	+18.3 to +24.5	<0.001
UAS (sUAS vs FANS)	–11.95	–14.48 to –9.43	<0.001
Laser source			
Magnetot vs TFL	–0.30	–3.23 to +2.63	0.84
p-Tm:YAG vs TFL	–1.70	–5.00 to +1.60	0.31
Laser power (watts)			
10 W vs 6 W	+1.18	–1.85 to +4.20	0.44
32–40 W vs 6 W	–0.94	–5.66 to +3.78	0.69
Mean IRT (°C)	+0.06	–0.27 to +0.38	0.73
Reference categories: TFL (laser), gravity irrigation, sUAS, 6 W. Model fit: R ² = 0.67.			

Fig. 2 Correlation between IRT and IRP ($r = -0.385$, $P < 0.001$).

completely independent physiological mechanisms. Furthermore, other pressure-related parameters, such as peak pressure, pressure variability, or cumulative exposure above clinically relevant thresholds, were not assessed in the present study and may also influence intrarenal thermal behaviour.

All thermal risk analysis in this study was referenced against the critical threshold of 43 °C, which is commonly used as a surrogate marker of potential thermal injury during ureteroscopy [15]. Although this threshold is widely accepted, our silicone model does not allow direct assessment of biological tissue damage; therefore, temperatures exceeding 43 °C should be interpreted as indicators of potential thermal risk rather than evidence of actual tissue injury.

Mean IRT increased in a dose-dependent manner with higher power settings, and the proportion of experiments exceeding 43 °C rose from <3% at 6 W to >40% at 40 W. This observation supports previous experimental data indicating that heat generation during laser lithotripsy is proportional to delivered energy and underscores the potential thermal hazard of sustained high-power settings, particularly under suboptimal cooling conditions [4,11,16,17].

Gravity irrigation was associated with significantly higher temperatures and a markedly higher incidence of thermal risk compared with hand-pump irrigation. Notably, hand-pump irrigation nearly abolished the occurrence of temperatures above 43 °C, even at high power settings. This is consistent with prior experimental reports suggesting that continuous liquid irrigation contributes to maintaining safer temperature profiles during laser activation [18]. Studies using porcine models have observed that unrestricted temperature rise above the 43 °C threshold occurs when irrigation is limited and that continuous irrigation markedly mitigates this effect [17,19].

Although the use of FANS did not predict mean IRT in all models, it significantly decreased the probability of exceeding the thermal-risk threshold, suggesting that enhanced outflow may contribute to lower peak temperatures. As expected, mean IRP was mainly affected by irrigation conditions and UAS configuration: hand-pump irrigation increased IRP, whereas FANS significantly reduced it. The role of UAS in maintaining lower pressure and facilitating outflow has been emphasised in prior studies, where appropriate sheath use helped prevent high IRP spikes, particularly when using aspiration sheaths [20,21]. Hand-pump irrigation and FANS use therefore appear to act synergistically to improve thermal and pressure conditions during laser lithotripsy. Although improved convective heat removal is a plausible explanation for the thermal benefit, irrigation flow was not directly measured in our model and therefore the underlying mechanism cannot be confirmed.

Regarding the laser source, p-Tm:YAG produced slightly higher mean IRT than TFL in our multivariate model, whereas the Ho:YAG Magneto did not differ significantly from TFL. However, when stratified by laser power, no significant differences in mean IRT were observed between devices. Molina et al. [14] similarly reported no significant difference in median IRT between Ho:YAG and TFL under high-frequency dusting settings (0.1–0.3 J $\times$ 70–200 Hz), whereas Belle et al. [22] found higher ureteric fluid temperatures with TFL across all tested power levels when compared with Ho:YAG in an *in vitro* model. This apparent discrepancy may reflect the different experimental conditions employed: studies reporting higher temperatures with TFL often used high-frequency dusting settings and limited outflow, favouring localised heat accumulation, whereas our model assessed mean IRT across multiple locations under standardised conditions, reflecting global rather than focal thermal behaviour. Taken together, these findings suggest that energy delivery and irrigation dynamics may exert a greater influence on thermal behaviour than laser source type alone.

Temperatures were higher in the renal pelvis than in the calyces, reflecting the proximity of the pelvic sensor to the laser fibre. This thermal gradient therefore represents near-field laser heating, whereas calyceal measurements reflect more distal heat dispersion influenced by intrarenal flow. In contrast, IRP behaves differently; in a closed fluid-filled system such as the renal collecting system, pressure transmission follows Pascal's law [23], whereby an applied pressure is transmitted throughout the enclosed fluid and equilibrates rapidly under steady-state conditions. Importantly, mean IRP was not a predictor of mean IRT nor thermal risk in the multivariable models, although an inverse correlation was observed, with higher mean pressure levels associated with lower mean temperatures. This association may reflect differences in irrigation dynamics and heat

dissipation; however, causal interpretation is limited by the interconnected nature of the irrigation variables.

Although derived from an experimental model, these findings may have important clinical implications. Unsafe thermal conditions appear to arise from a combination of high energy delivery and inadequate heat dissipation. High-power laser settings should therefore be used cautiously when irrigation flow is limited, and strategies that enhance convective cooling and outflow may substantially reduce thermal risk [24,25]. Although intermittent laser activation is frequently advocated as a strategy to reduce thermal exposure, available evidence suggests that temperature reduction following laser cessation may be delayed [16], and the protective effect of on–off activation patterns is likely to depend on the duration of inactive periods and the efficiency of irrigation-mediated cooling.

This study has several limitations. It was conducted in an *in vitro* model that cannot fully reproduce the anatomical, biomechanical, and physiological characteristics of the human collecting system. Although the silicone model exhibits a degree of compliance, its mechanical behaviour differs from that of native renal tissue and does not fully replicate dynamic changes in collecting-system distensibility, urine production, renal perfusion, or the response to negative-pressure conditions. The IRP values observed, particularly under suction conditions, should be interpreted cautiously and the findings are likely more informative regarding relative differences between configurations than exact values expected *in vivo*.

Additionally, BegoStone phantoms were used to standardise laser–stone interactions, but their thermal and physical properties may differ from those of human urinary calculi. Finally, irrigation flow was not directly measured, limiting mechanistic interpretation of the thermal and pressure observations.

Nevertheless, the controlled design allowed relative isolation of individual factors and revealed consistent and physiologically plausible relationships between energy delivery, flow dynamics, pressure, and temperature.

Collectively, our findings support the potential value of advanced integrated irrigation–aspiration systems capable of dynamically balancing inflow and outflow to minimise both thermal and pressure-related risks during high-power laser lithotripsy, consistent with recommendations from recent reviews [26,27].

Conclusions

In this experimental model, mean IRT during laser lithotripsy was primarily associated with laser power and irrigation strategy. Higher power settings substantially increased IRT and the risk of exceeding the thermal-risk threshold, whereas

hand-pump irrigation significantly reduced both mean IRT and thermal risk compared with gravity irrigation. Although the use of FANS was not a predictor of lower mean IRT, it showed a protective effect against exceeding the thermal-risk threshold. Laser technology had no impact on IRT when power and irrigation conditions were comparable in this experimental setting. Mean IRP was mainly influenced by irrigation modality and UAS configuration but was not associated with mean IRT. Given the interdependence between irrigation, outflow, and pressure dynamics, our results should be interpreted within the context of the experimental conditions evaluated. These findings underscore the need for advanced integrated irrigation–aspiration systems capable of dynamic control of flow, pressure, and temperature to optimise procedural safety.

Author Contributions

Alejandra Bravo-Balado: conceptualisation; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualisation; roles/writing – original draft; writing – review and editing. Letizia Maria Ippolita Jannello: data curation; validation; visualisation; roles/writing – original draft; writing – review and editing. Federico Zorzi: data curation; validation; visualisation; roles/writing – original draft; writing – review and editing. Alberto Quarà: data curation; validation; visualisation; roles/writing – original draft; writing – review and editing. Stefano Moretto: data curation; validation; visualisation; roles/writing – original draft; writing – review and editing. Mariela Corrales: conceptualisation; funding acquisition; methodology; project administration; validation; visualisation; writing – review and editing. Esteban Emiliani: conceptualisation; funding acquisition; investigation; methodology; project administration; supervision; validation; visualisation; writing – review and editing. Steeve Doizi: investigation; methodology; project administration; resources; validation; visualisation; writing – review and editing. Frédéric Coste: methodology; project administration; resources; supervision; validation; visualisation; writing – review and editing. Olivier Traxer: conceptualisation; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualisation; writing – review and editing. Frédéric Panthier: conceptualisation; data curation; investigation; methodology; project administration; resources; software; supervision; validation; visualisation; roles/writing – original draft; writing – review and editing.

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Disclosure of Interests

Olivier Traxer has declared as consultant for Karl Storz, Coloplast, IPG photonics, Ambu, Quanta System and Rocamed. Frédéric Panthier has declared as consultant for Dornier Medtech. The remaining authors have no disclosures.

Ethics Approval

Ethical approval was waived by the local Ethics Committee of our institution because no patient data were involved.

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Declaration of Generative Artificial Intelligence (AI) and AI-Assisted Technologies in the Manuscript Preparation Process

During the preparation of this work, the authors used Chat Generative Pre-Trained Transformer (ChatGPT; OpenAI, Inc., San Francisco, CA, USA) to assist with language editing and grammar refinement. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Data Availability Statement

All data and Python scripts are available from the corresponding author upon reasonable request.

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Abbreviations: FANS, flexible and navigable suction sheaths; Ho:YAG, holmium:yttrium-aluminium-garnet; IRP, intrarenal pressure; IRT, intrarenal temperature; OR, odds ratio; p-Tm: YAG, pulsed thulium:YAG; TFL, thulium fibre laser; (s)UAS, (standard) ureteral access sheath(s).

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Intrarenal temperatures across the different experimental settings.

Table S2. Intrarenal pressures across the different experimental settings.