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Review

Factors affecting the thermal effects of lasers in lithotripsy: A literature review

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KEYWORDS
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Abstract *Objective:* The use of lasers has been an important part of urology in the treatment of stone and prostate disease. The thermal effects of lasers in lithotripsy have been a subject of debate over the years. The objective of this review was to assess the current state of knowledge available on the thermal effects of lasers in lithotripsy, as well as explore any new areas where studies are needed.
Methods: In August 2022, a keyword search on Google Scholar, PubMed, and Scopus for all papers containing the phrases "thermal effects" AND "laser" AND "lithotripsy" AND "urology" was done followed by citation jumping to other studies pertaining to the topic and 35 relevant papers were included in our study. The data from relevant papers were segregated into five groups according to the factor studied and type of study, and tables were created for a comparison of data.
Results: Temperature above the threshold of 43 °C was reached only when the power was >40 W and when there was adequate irrigation (at least 15—30 mL/min). Shorter lasing time divided by lithotripsy time or operator duty cycles less than 70% also resulted in a smaller temperature rise.
Conclusion: At least eight factors modify the thermal effects of lasers, and most importantly, the use of chilled irrigation at higher perfusion rates, lower power settings of <40 W, and with a shorter operator duty cycle will help to prevent thermal injuries from occurring. Stones impacted in the ureter or pelvi-ureteric junction further increase the probability of thermal injuries during laser firing.

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1. Introduction

Laser is an acronym for "light amplification by stimulated emission of radiation". In 1968, Mulvaney and Beck [1] published a study on the fragmentation of calculi using a ruby crystal laser, which was one of the first studies in laser lithotripsy. The use of lasers has been an important part of urology in the treatment and management of stone diseases and benign prostatic hyperplasia especially after the 1980s. The urological community would benefit from a review article that provides an overview of the current state of knowledge on the thermal effects of lasers, as well as identifies potential new areas of research that require further investigation. Also, the safety of the long-term use of lasers on injury to the pelvicalyceal system and the ureters as well as the factors that may lead to causation of this photothermal injury is not well documented and requires further detailed studies.

During laser lithotripsy, the operator can modify three factors to achieve the necessary effect of stone fragmentation: pulse energy (J), pulse frequency (Hz), and pulse duration (μs). Any changes in energy and frequency can change the power (W), and higher power results in higher temperatures and therefore thermal damage [2]. This thermal damage occurs as a result of the photothermal effect of lasers leading to absorption of the heat energy by the surrounding tissue [3].

Temperature measured using thermocouples placed near the laser probe has been the surrogate used in various experimental studies to extrapolate on safety of *in vivo* laser use. Sapareto and Dewey [4] proposed a "time—temperature relationship" for tissue thermal damage stating that for every 1 °C exceeding the "threshold (43 °C)", the time required to cause damage to the same number of cells will decrease by half. For example, when the tissue is in a 45 °C environment for 15 s, the degree of thermal damage to cells is similar to that at 44 °C for 30 s or 43 °C for 1 min. Most of the articles in this review used this temperature threshold as the standard for assessing the thermal end point.

A long-term sequela of thermal injury of particular concern is that of ureteral strictures. It was found to be approximately three times more common in patients treated by laser lithotripsy over pneumatic lithotripsy in a meta-analysis study [5]. However, a prospective study published in 2019 found that the incidence rate was quite low (1.5%) and seen mostly in the presence of stone impaction [6]. Whether this result was due to an increase in the local temperature or direct injury to the surrounding tissue could not be determined. This is an area of interest which may need further investigation and can be considered for future studies.

The objectives of this review article were to study the following questions in relation to lasers in lithotripsy.

i. What were the factors affecting the thermal effects of lasers on non-target tissue during lithotripsy?
ii. Was the thermal injury to non-target tissue during laser lithotripsy significant?
iii. What were the areas that need further investigation to prevent laser-related injuries?

2. Materials and methods

In August 2022, a keyword search on Google Scholar, PubMed, and Scopus for all papers containing the keywords "thermal effects" AND "laser" AND "lithotripsy" AND "urology" was done in various combinations, followed by citation jumping to other studies pertaining to the topic. All accepted and published English language full articles were studied and filtered wherein articles not pertaining to the aims of our review were excluded by reading the title, abstract, and full article. Thirty-five relevant papers were included in our study and the findings are presented as a narrative literature review.

There were several factors that stood out while the review was conducted and they were segregated into five groups according to the factor studied and type of study, and tables were created for a comparison of data.

3. Results

3.1. Irrigation

The majority of the studies were done on irrigation (its presence or absence, with irrigation pump or only gravity, and chilled or warm). Out of 12 studies, two were *in vivo* in sheep or pig [7,8], two were *ex vivo* [9,10], while the remaining eight [2,11—17] were *in vitro* studies. They all used thermocouples for measuring the temperature but the placement of the probe was inconsistent among the studies. An average distance of 0.5 mm from the laser tip is ideal corresponding to the depth of penetration of holmium:yttrium-aluminium-garnet (Ho:YAG) laser in the water medium [18].

One of the first laser thermography study was conducted in 2015 by Molina et al. [9], where two *ex vivo* models (clinical model and open ureteral model) were studied for temperature rises during Ho:YAG laser with 365 μm firing at 10 W (1 J/10 Hz). They showed an increase in the temperature during laser activation and that ureteral thermal values decreased with saline irrigation. This was further cemented in 2016 by Butticè et al. [11], when they compared 200 μm with 272 μm fibers in a bench model inserted into a saline-filled heating tank at two temperatures (room 24.5 °C and body 36.5 °C). They found that when the irrigation was open, the maximum temperature limit was never reached. Dau et al. [8,16] conducted studies *in vivo* (in 2022) and *in vitro* (in 2021), respectively, most importantly studying the effect of chilled irrigation on caliceal fluid temperatures and the laser heating of fluid with and without stone ablation. They showed that the temperature rise and thermal dose during lithotripsy, especially at higher power were reduced by using chilled irrigation at 1 °C as compared to room temperature irrigation at 19 °C.

More studies since then have come to similar conclusions in various different settings as enumerated in Tables 1 and 2, and the general consensus was that irrigation is essential during laser activation preferably at higher flow rates and higher pressure. Most studies showed a temperature beyond the threshold of 43 °C, only at higher power settings (≥40 W), and the power of the laser must be regulated to stay below the threshold. One article also showed that high

Table 1 Studies pertaining to irrigation with the holmium:yttrium-aluminium-garnet laser.

Study	Study subject	Laser fiber used (μm)	Lasing time	Power setting (W or J/Hz)	Irrigation setting	Temperature recorded (°C)	Mode of temperature measurement
Molina et al., 2015 [9]	Ovis aries	365	NA	1/10	• With • Without	• 37.4±2.5[a] • 49.5±2.3[a]	• Temperature on external surface using Infrared Fluke Ti55 Thermal Imager
Butticè et al., 2016 [11]	Bench model with saline heating tank	200 or 272	Stopped when a limit reached	0.5/20, 1/10, 2/5, 3/5, or 4/5	• With or without	• Threshold surpassed when irrigation not used	• Endotracheal thermometer inside the model
Aldoukhi et al., 2017 [12]	Glass test tube	200	1 min	(0.5–1)/(10–80)	• 0, 7–8, 14–15, or 38–40 mL/min	• Max 70.3±2.7[a] at 40 W, no irrigation	• Thermocouple placed 5 mm from bottom of the test tube
Aldoukhi et al., 2018 [7]	Pig	242	1 min	0.5/80	• 0.1, 15, or 40 mL/min	• 0.1 mL/min: 84.8 • 15 mL/min: 63.9 • 40 mL/min: 43.6	• Thermocouples in calyx, by open exposure, puncture, and retrograde beside the scope
Wollin et al., 2018 [2]	PVC tubing	200	1 min	(0.2–1)/(6–50)	• 0, 50, or 100 mL/min	• 0 mL/min: >100 • 50 mL/min: >43.4 • 100 mL/min: 30.7	• Probe tip thermometer placed 1 mm from tip of fiber
Hein et al., 2018 [13]	20 mL test tube in water bath	272 or 940	2 min	0.5/33, 1/18, 1.5/30, 2/2, or 4.5/(4,12, or 22.3)	• 0–100 mL/min	• Max 68 at 100 W	• Thermocouple in the test tube and water bath
Winship et al., 2019 [17]	Saline bag with reservoir	365	45 s	(0.2–1)/(6–80)	• 0, 100, or 200 mmHg	• Threshold >6 rose at 100 mmHg and below	• Thermocouple placed adjacent to the fiber
Hein et al., 2020 [10]	Porcine kidney in water bath	272, 550, or 940	1min	5–100 W	• 0–100 mL/min	• Critical temperature rose above 30 W	• Three thermocouples in kidney with one flexible thermocouple placed 4 mm proximal to fiber
Ghanim et al., 2020 [14]	Water tank with PVC pipe	365	70 s	(0.375, 0.675, or 1)/20	• 0, 1, 10, or 30 mL/min	• Max 70 at high power and closest to thermometer	• Thermometer in one end of the PVC tube
Liang et al., 2020 [15]	Ligated F20 rubber tube	200	3, 5, or 10 s	(0.5, 1, 1.5, 2, or 3)/(10 or 20)	• 10, 15, 20, or 30 mL/min	• Max 78 at 30 W power at 10 mL/min	• Thermocouple 5 mm from bottom of the tube

(*continued on next page*)

Table 1 (*continued*)

Study	Study subject	Laser fiber used (μm)	Lasing time	Power setting (W or J/Hz)	Irrigation setting	Temperature recorded (°C)	Mode of temperature measurement
Dau et al., 2021 [16]	Glass test tube in water bath	242	1 min	0.5/80	• Chilled irrigation at 1 °C and room temperature at 19 °C at 0, 8, 12, 15, or 40 mL/min	• Threshold temperature delayed in chilled	• Wire thermocouple 3 mm proximal to the ureteroscope tip
Dau et al., 2022 [8]	Female Yorkshire pig	242	1 min	NA	• Chilled irrigation at 1 °C to 4 °C and room temperature at 19 °C at 0–40 mL/min	• Threshold temperature delayed in chilled	• Thermocouple fixed 5 mm from the ureteroscope tip

Max, maximum; NA, not available; PVC, polyvinyl chloride.
[a] Mean±standard deviation

energy (3.0 J) and low frequency (10 Hz) mode has slightly less thermal damage than its counterpart settings at the same power [15] and needs further evaluation.

The use of ureteric access sheath (UAS) and its effect on the intrarenal temperature were also studied by one group [19]. They found that the UAS decreases intrarenal temperatures at a power setting of 20 W, when compared with not using one. At a power setting greater than 40 W, however, the protective effect was lost and only remedied by increasing irrigation rates [19]. This study also compared the use of the manual pump with the gravity pump for irrigation, and observed that the dangerous threshold temperature was never reached with the manual pump (0.33 pumps/s), but the temperature rise was detrimental at the higher power of >40 W with the gravity pump. Therefore, this indicates that the manual pump could be preferred over the simple gravity irrigation.

3.2. Type of laser

Apart from the Ho:YAG laser, another laser being used frequently recently in lithotripsy is the thulium:YAG (Th:YAG) laser. Since the Th:YAG (2000 nm) laser has a slightly lesser wavelength compared with the Ho:YAG (2140 nm), the depth of penetration is also less. The power efficiency of Th:YAG laser is also said to be five times more than the Ho:YAG laser [18]. But the main advantage during lithotripsy for the Th:YAG is that it is a continuous wave laser, which is better suited for tissue ablation; to overcome this, a thulium fiber laser (TFL; 1940 nm wavelength) was introduced, which was a thulium ion laser with semiconductor diodes instead of a flash pump [20]. This TFL had both the continuous and pulsed wave modes.

The major aspects of studies comparing the Ho:YAG with thulium laser have been summarized in Table 3. In 2016, Kallidonis et al. [21,22] performed two separate studies to evaluate the effect of the Th:YAG laser when compared with Ho:YAG laser. One was *ex vivo* in the porcine upper urinary tract, while the other was an *in vitro* model. They showed comparable results in both studies while studying the temperature rises using both lasers, and concluded that up to 20 W Th:YAG laser was a safe alternative to the Ho:YAG laser, with adequate irrigation. Similar results were obtained by Taratkin et al. [23] and Peng et al. [24] when comparing the Ho:YAG laser with the TFL, finding that irrigation reduced the respective temperatures in the same manner for both lasers.

More recently, Molina et al. [25] compared the temperature rise seen during the super pulse TFL versus the high power Ho:YAG laser during dusting and fragmenting separately in *ex vivo* porcine kidneys. The intra-luminal temperature rise during laser activation was equivalent during dusting and higher in the super pulse TFL during fragmentation, but neither reached the threshold for thermal injury based on the duration of exposure. Therefore, there seems to be a risk of an increased temperature rise with a TFL during fragmentation, but it warrants further investigation.

3.3. Operator duty cycle (ODC) and pedal time

The ODC indicates the ratio of "on/off" of the laser power. The higher the "duty", the higher the ratio of "on"

Table 2 Inferences from the irrigation studies.

Study	Inference
Molina et al., 2015 [9]	• The study was one of the first studies that showed an increase in the temperature during laser activation and that ureteral thermal values decreased with saline irrigation
Butticè et al., 2016 [11]	• Rapid increases of temperature must be avoided when irrigation is closed and water at lower temperatures during irrigation helped delay the rise of temperature
Aldoukhi et al., 2017 [12]	• The highest temperature seen with 1 J/40 Hz power and no irrigation, counter measures for same can be exploited by urologists
Aldoukhi et al., 2018 [7]	• Thermal damage threshold reached in no and medium irrigation but not in high irrigation, so high-power lasers pose a threat for thermal damage at lower irrigation rates
Wollin et al., 2018 [2]	• Despite increasing laser settings, adequate irrigation can maintain relatively stable temperatures within an *in vitro* ureteral system
Hein et al., 2018 [13]	• Laser devices should, therefore, always be applied in conjunction with continuous, closely monitored irrigation whenever performing holmium:yttrium-aluminium-garnet laser lithotripsy
Winship et al., 2019 [17]	• High temperatures were achieved in as little as 1 s at common irrigation pressure and laser settings, particularly with a flexible ureteroscope and power $\geq$10 W; however, with laser cessation, temperatures quickly returned to a safe level at each irrigation pressure
Hein et al., 2020 [10]	• A formula to calculate the approximate ΔT for irrigation rates $\geq$30 mL/min was developed: ΔT=15 K$\times$(power [W]/irrigation [mL/min])
Ghanim et al., 2020 [14]	• All three parameters (pulse energy, irrigation rate, and distance) showed highly significant effect on measured temperatures; the holmium:yttrium-aluminium-garnet laser might be safely provided when there was sufficient irrigation with optimal selected laser power
Liang et al., 2020 [15]	• Safe temperature of laser firing can be ensured at laser power less than 10 W, irrigation greater than 30 mL/min, and high-energy low-frequency firing
Dau et al., 2021 [16] and Dau et al., 2022 [8]	• Chilled irrigation slows temperature rise, decreases plateau temperature, and lowers thermal dose during high-power laser lithotripsy

compared with "off", and therefore, it gives more output energy. The 100% ODC means continuous on, which is the continuous wave cutting [26]. In the setting of lithotripsy, it may be calculated as lasing time divided by lithotripsy time.

In 2021, Aldoukhi et al. [27] performed *in vitro* tests, wherein 1200 J of laser energy was applied in five different patterns at 20 W average power for 60 s. The mean ODC was 32% overall among the five patterns and the mean time of pedal activation was 3.6 s. *In vitro* studies revealed a longer pedal activation time produced a higher peak temperature and thermal dose. Louters et al. [28] in 2022, conducted a similar study to determine the effect of the ODC on the thermal dose delivered. A higher ODC resulted in a greater maximum temperature and thermal dose, with an ODC $\geq$70% exceeding the threshold of 43 °C. Use of a 50% ODC compared with 60% of the ODC resulted in a ten-fold increase in time required to reach the threshold of thermal injury and an eight-fold increase in maximal allowable energy. These studies fortify the statement that judicious laser ODC control can help to prevent thermal damage from lasers.

3.4. *In vivo* studies

One of the only *in vivo* studies was conducted in patients undergoing ureteroscopy laser lithotripsy for stone disease in China in 2019 by Wang et al. [29]. A total of 30 patients (16 males and 14 females) with a mean age of 47.4 (standard deviation 13.7) years, and a mean calculi diameter of 14.2 (standard deviation 8.1) mm, undergoing ureterorenoscopic lithotripsy were studied. A temperature measurement guidewire was inserted and extended slightly beyond the ureteroscope, while the other end was connected to a thermometer that fed real-time temperature change data to a computer.

The highest temperatures in the 30 sets of data were all higher than 43 °C (100%), with 19 sets (63.3%) having peak temperatures higher than 56 °C. This study showed that with the increase in the power of the holmium laser, or with impacted calculi, the increase in the temperature of the lavage solution around the calculi was even greater, often exceeding the temperature that could be safely tolerated by the tissue; therefore, temperature might be one of the factors that caused ureteral thermal injury and resulted in postoperative strictures [24]. However, the study by Wang et al. [29] was not without limitations as it only studied the thermal effect with respect to the laser power, and also the surgeon was different for each case, which meant the laser settings, time of lasing, and intraoperative conditions were different for each case.

3.5. Other factors like volume and pulse duration

In 2022, Dau et al. [30] performed an *in vitro* study keeping the laser fiber above the stone at 3.5 mm (no ablation) and 0.5 mm (ablation), and the temperature of the fluid was recorded using two thermocouples once per second, to determine the percentage of applied laser energy that is converted to heat and the percentage used for stone ablation. They found that even under conditions of energy-efficient stone ablation, the majority of applied laser energy (91%—96%) was converted to heat [30]. The pelvicalyceal volume in which laser activation occurs was also later found to be an important factor in the thermal effects caused

Table 3 Studies pertaining to the type of lasers.

Study	Study subject	Laser studied	Laser fiber diameter or type	Lasing time	Power settings (W), energy (J)/frequency (Hz)	Irrigation setting	Temperature recorded (°C)
Kallidonis et al., 2016 [21]	Pig	Ho:YAG *vs.* Th:YAG	Continuous wave	NA	• 10 W, 20 W, 30 W, or 40 W	• With	• 33.5
Kallidonis et al., 2016 [22]	Burette with a stopcock and a 40 mL vessel	Ho:YAG *vs.* Th:YAG	Both pulsed and continuous waves	10 min	• 5 W, 10 W, 20 W, 50 W, or 100 W	• Without	• 45.6–68.7
Taratkin et al., 2020 [23]	*In vitro* model	Ho:YAG *vs.* SP TFL	200 μm	1 min	• 40 W, 0.2 J	• 0 or 35 mL/min	• Temperature reduction after irrigation - Ho:YAG: 2.6 - TFL: 1.9
Peng et al., 2020 [24]	Test tube in water tank	TFL	Continuous wave	1 min	• Different settings up to 30 W	• 0, 15, 25, or 50 mL/min	• 0 and 15 mL/min: more than 6.5 °C rise above threshold seen; 25 and 50 mL/min: no rise of temperature over threshold
Molina et al., 2021 [25]	Porcine kidney	Ho:YAG *vs.* SP TFL	200 μm	5 s each for 15 times	• Ho:YAG dusting: 0.3 J/70 Hz; SP TFL dusting: 0.1 J/200 Hz; fragmenting: 0.8 J/8 Hz	• With	• During fragmenting setting - Ho:YAG: 30 - SP TFL: 33.3 • During dusting setting - Ho:YAG: 35.8 - SP TFL: 40.6

Ho:YAG, holmium:yttrium-aluminium-garnet; Th:YAG, thulium:yttrium-aluminium-garnet; TFL, thulium fiber laser; SP, super pulse; NA, not available.

by lasers [31]. The authors found that the volume of fluid in each model was inversely related to the extent of temperature elevation. Therefore, the thermal dose in laser firing reached the threshold for injury faster in smaller volumes. Louters et al. [32] performed a study to determine the volume of fluid mixing during laser activation in a plastic tube with dyed irrigation by evaluating the distance travelled by the dyed fluid during laser activation. The volume of total fluid mixing within the ureter model was found to be small, thus conferring a greater risk of ureteral thermal injury.

The pulse duration of laser activation has also been found to play a role in the thermal effects in a study by Sugiwaka et al. [33] in 2022, where the bubble behavior and temperature distribution around bubbles were studied in an *in vitro* experiment. They found long pulse bubbles had a higher temperature around the bubble and may lead to increased thermal damage to surrounding tissue. The factors mentioned above have not been studied in detail enough to know whether they influence the thermal damage to much extent. However, they should be considered in subsequent analyses, as preliminary studies show that they do play a role.

The main study parameters and settings with respect to these factors are listed in Table 4.

4. Discussion

The use of lasers for lithotripsy is widespread with newer technology and different lasers being developed for this specific purpose. The photothermal effect as mentioned earlier is the main mechanism for the fragmentation of stones, but there are some factors of the laser and fiber used that can modify these effects to a certain extent. At higher power, irrigation is required at higher flow rates to keep temperatures low. However, one must be judicious as overzealous pumping of irrigation can lead to pyelovenous backflow and extravasation due to an increased intrarenal pressure [34].

High-power laser energy can cause a significant increase in fluid temperature in the collecting system and ureter, leading to histologic injury in the surrounding tissue [2,7,12,17]. It is crucial to develop methods to predict and control the thermal dose to ensure patient safety during high-power laser lithotripsy. As mentioned earlier, the time duration of temperature also plays an important role as elucidated in the "time–temperature relationship" by Sapareto and Dewey [4]. This is further encountered as the ODC, or the time duration of "on/off". One study has shown that while the temperature may reach below the threshold between laser firing attempts, the thermal dose is cumulative and can reach very large proportions [27]. Therefore, it is essential that these factors which may lead to an increased thermal dosage are studied in order to prevent thermal damage, especially in the *in vivo* settings. This study attempted to consolidate the various factors that modify the thermal effects of lasers, so that future studies may concentrate their efforts in studying these factors in detail.

From our review, it can be inferred that there are at least eight factors that modify the thermal effects of lasers:

i. Irrigation: the irrigation at higher perfusion flow rates with open systems, at higher pressure, and chilled irrigation over warm irrigation provided better control of the temperature rise during laser lithotripsy. A UAS when feasible may be recommended to reduce temperatures.
ii. The type of laser: the TFL may have slightly higher potential for damage, but further studies are required.
iii. Power settings: in general, higher power means increased risk for damage. Staying below a maximum of 40 W is advisable.
iv. The ODC and pedal time: the higher ODC (on time > off time) and longer pedal times increase risk for injury. Intermittent lasing should be advocated as opposed to continuous.
v. Pulse duration: longer pulse duration increase temperature around bubble and thereby can cause damage.
vi. Volume of fluid: this includes the total pelvicalyceal volume in which laser activation occurs as well as the volume of fluid mixing, with lower fluid volumes resulting in increased thermal doses.
vii. The distance from stone: preliminary studies show that the energy transfer may be equivalent at further distances as well; however, more studies are needed to come to an apt conclusion.
viii. Stone impaction: with impacted stones, the temperature of the lavage solution was significantly higher, often exceeding the temperature that could be safely tolerated by the tissue.

There are plenty of studies to show the importance of the first three factors, and further studies should focus on the remaining lesser researched factors to ensure that thermal injury can be completely avoided during laser activation.

The major deficiency in the studies was that none of them assessed how the temperature changes actually affect the physiology of the pelvi-ureteric system and kidney function due to their *in vitro* nature. There are obvious ethical issues that come up as well that prevent one from experimenting at higher temperature at the cost of safety. However, one is encouraged to pursue more randomized control human studies comparing temperature changes at laser settings below 40 W, at different irrigation rates (preferably chilled), and at lower ODCs (*i.e.*, intermittent activation) in order to find the ideal settings for safety. The use of a UAS and manual pump during irrigation can also be seen to help mitigate the temperature rise seen during laser activation, and more studies are advised comparing the manual pump with gravity irrigation both with and without access sheaths.

Our study had some limitations notably that the reviewed data were mostly from experimental studies conducted on various *in vitro*, *in vivo*, and *ex vivo* subjects, and not clinical data from patients. Also notably, it was a narrative study that reflects the heterogeneity of data, such as the various laser settings, lasers used, and flow rates. As the adage goes, "prevention is better than cure", and additional research is required to prevent laser thermal damage.

Table 4 Other factors affecting thermal damage by lasers.

Study	Factor studied	Study subject	Laser studied	Laser fiber diameter and laser setting	Lasing time	Power settings (J/Hz)	Irrigation setting	Temperature recorded
Dau et al., 2022 [30]	Percentage of laser energy converted to heat	Double walled glass Dewar	Moses 200 D/F/L	200 μm, short pulse and Moses distance modes	30 s	0.5/5	NA	• Rise in control: 1.03±0.01 °C[a] • Rise in experiment: 0.99±0.06 °C[a]
Rezakahn Khajeh et al., 2022 [31]	Pelvicalyceal system volume	Glass tubes of different volumes in the water tank	Ho:YAG laser	230 μm	1 min	0.5/80	0, 8, 15, or 40 mL/min	• Threshold reached faster in smaller volume
Tsaturyan et al., 2022 [36]	Continuous prolonged activation	20 mL syringe with the access sheath	Ho:YAG laser	Continuous wave	10 min	(0.3, 1, or 1.5)/40	10, 20, or 30 mL/min	• Max 83 °C at 10 mL/min
Sugiwaka et al., 2022 [33]	Pulse duration	*In vitro* model	NA	Pulsed wave	NA	NA	NA	• NA
Louters et al., 2022 [32]	Volume of fluid mixing	Plastic tube	Ho:YAG laser	NA	NA	0.5/40	8–40 mL/min	• Threshold crossed at lower irrigation rates with the mixing volume only 1.26±0.10 cm^3[a]

Ho:YAG, holmium:yttrium-aluminium-garnet; Max, maximum; NA, not available.
[a] Mean±standard deviation.

5. Future perspective

It is well known that the theoretical depth of penetration of the Ho:YAG laser into tissue is only 0.4 mm, but there has been speculation that the actual depth of penetration exceeds it [35]. This may account for the thermal damage seen during the use of lasers. However, whether the injury was related to contact damage or due to the thermal effects of the heat generated by laser firing has not been studied in depth. Whether it is due to either cause, the risks that stem from thermal damage cannot be easily ignored and thus the factors which may influence this damage have to be studied thoroughly.

Many studies in the past decade have been dedicated to studying the effects of irrigation on the thermal damage caused; however, the recent studies focused more on other factors such as pulse duration, ODC, type of laser, and *in vivo* studies. These need to be studied further in detail to fill the voids in our knowledge regarding the impact these factors have on laser related injury. In addition, there is a lack of studies which consider patient factors like age, degree of hydronephrosis, and coexisting infections; this may confound the temperature rise seen. However, this is probably due to the fact that the majority of studies are *in vitro* ones, and when *in vivo* studies are done in the future, these factors should be studied prudently.

6. Summary

This review explores the thermal effects of lasers in urology, particularly in lithotripsy for stone and prostate disease. The study was conducted by searching for relevant papers on thermal effects, lasers, lithotripsy, and urology. A total of 35 papers were included in the study, and the results were categorized into five groups for analysis. The findings reveal that temperatures above 43 °C are typically reached with laser power exceeding 40 W and sufficient irrigation (at least 15—30 mL/min). Shorter lasing times and an ODC of less than 70% also lead to smaller temperature increases. The study concludes that several factors influence the thermal effects of lasers including the irrigation, type of laser, power, ODC, pulse duration, volume of fluid, and stone impaction. The key recommendations from the study include the use of chilled irrigation at higher perfusion rates, lower power settings (<40 W), and a shorter ODC to prevent thermal injury, especially in cases involving impacted stones.

7. Conclusion

The thermal effect of lasers with respect to urology is one of the up-and-coming areas of research, even though studies date almost back to 2015. A better understanding of the thermal injury that may result from lasers is essential to prevent the improper technique and consequent sequelae. The use of chilled irrigation at higher perfusion rates, lower power settings of <40 W, and with a shorter ODC will help to prevent thermal injuries from occurring, especially during stone impaction. This review article hopes to highlight the important lessons to be learnt from previous studies and encourage the reader to endeavor into the various gaps in knowledge which are present to further ensure safe and efficient laser usage.

Author contributions

Study concept and design: Kiron Krishnaprasad.
Data acquisition: Kiron Krishnaprasad, Ravi Teja Pathi.
Data analysis: Kiron Krishnaprasad.
Drafting of manuscript: Kiron Krishnaprasad, Ravi Teja Pathi.
Critical revision of the manuscript: Kiron Krishnaprasad, Mustafa Nazar.

Conflicts of interest

The authors declare no conflict of interest.

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