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TOPIC PAPER

# Experts' recommendations in laser use for the treatment of upper tract urothelial carcinoma: a comprehensive guide by the European Section of Uro-Technology (ESUT) and Training Research in Urological Surgery and Technology (T.R.U.S.T.) group

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## Abstract

**Purpose** To highlight and compare experts' laser settings during endoscopic laser treatment of upper tract urothelial carcinoma (UTUC), to identify measures to reduce complications, and to propose guidance for endourologists.

**Methods** Following a focused literature search to identify relevant questions, a survey was sent to laser experts. We asked participants for typical settings during specific scenarios (ureteroscopy (URS), retrograde intrarenal surgery (RIRS), and percutaneous treatment). These settings were compared among the reported laser types to find common settings and limits. Additionally, we identified preventive measures commonly applied during surgery.

**Results** Twenty experts completed the survey, needing a mean time of 12.7 min. Overall, most common laser type was Holmium–Yttrium–Aluminum–Garnet (Ho:YAG) (70%, 14/20) followed by Thulium fiber laser (TFL) (45%, 9/20), pulsed Thulium–Yttrium–Aluminum–Garnet (Tm:YAG) (3/20, 15%), and continuous wave (cw)Tm:YAG (1/20, 5%). Pulse energy for the treatment of distal ureteral tumors was significantly different with median settings of 0.9 J, 1 J and 0.45 J for Ho:YAG, TFL and pulsed Tm:YAG, respectively ($p = 0.048$). During URS and RIRS, pulse shapes were significantly different, with Ho:YAG being used in long pulse and TFL in short pulse mode (all $p < 0.05$). We did not find further disparities.

**Conclusion** Ho:YAG is used by most experts, while TFL is the most promising alternative. Laser settings largely do not vary significantly. However, further research with novel lasers is necessary to define the optimal approach. With the recent introduction of small caliber and more flexible scopes, minimal-invasive UTUC treatment is further undergoing an extension of applicability in appropriately selected patients.

**Keywords** Laser · UTUC · RIRS · URS · Percutaneous · Urothelial cancer

## Introduction

Upper tract urothelial carcinoma (UTUC) is a rare disease with an estimated annual incidence in Western countries of 2/100.000 individuals [1]. Radical nephroureterectomy (RNU) represents the standard of care; however, with advances in modern endourology [2], endoscopic treatment for low-risk tumors with limited disease extent or high-risk tumors in solitary kidneys [1, 3] is a feasible option offering acceptable oncological outcomes [1]. Lasers, such as Holmium–Yttrium–Aluminum–Garnet (Ho:YAG) [4, 5], combined Thulium–Holmium:YAG [6, 7], continuous wave (cw) Thulium–Yttrium–Aluminum–Garnet (Tm:YAG) [8], and Thulium fiber (TFL) [9, 10], are the mainstay of endoscopic UTUC treatment and have demonstrated clinical applicability. Nevertheless, little is known about the optimal laser and optimal laser settings [11] in this field of endourology. To address this knowledge gap, we conducted an online survey among renowned laser experts to reveal contemporary laser settings for various laser sources and important features for

Extended author information available on the last page of the article

successful UTUC treatment. We aimed to provide valuable guidance for clinicians to improve patient outcomes and stimulate further research regarding laser UTUC treatment.

## Methods

### Identification of relevant questions

We performed a literature search using the Pubmed database to identify the relevant literature on endoscopic laser treatment for UTUC. Search terms consisted of variant combinations of the following keywords: “urothelial cancer,” “upper tract,” “UTUC,” “laser,” “Ho:YAG,” “TFL,” “Tm:YAG,” “settings,” “kidney,” “ureter.” The literature was then screened by the two principal authors (GO and TT) to identify relevant questions regarding laser settings. The limitations of using a single database for review are taken into account [12].

### Definitions of outcomes

The primary outcome was to identify significant laser settings (laser energy, laser power, and laser frequency) during different clinical scenarios of UTUC treatment with comparisons of median and maximum settings among the available laser sources. Secondary outcomes were.

- specific laser settings (pulse shapes and pulse modifications),
- limitations (morphological tumor characteristics and technical aspects during surgery), and
- preventive measures applied by experts to reduce complications.

### Survey construction

Fifty-one questions were created (Supplementary Fig. 1). Possible answers were either binary, ordinal, categorical, or continuous type. To identify specific laser settings, we focused on various scenarios (e.g., ureteroscopy (URS), retrograde intrarenal surgery (RIRS), and percutaneous nephrolithotomy (PCNL)). Participants were able to select a maximum of two laser types. We used the Sosci-survey tool (Medical University Innsbruck, https://sosci.i-med.ac.at) to create the online survey, supporting anonymous survey processing. Our expert selection list was created by the senior author (TT) and discussed with three contributing senior authors (UN, TRWH, and AG). The list included board and associate members of the ESUT (endoscopy–upper tract) group and international experts outside Europe. Final selection was based on both clinical experience and scientific contribution in the field.

### Statistical analysis

Due to the mainly skewed distribution (graphical analysis), we reported continuous variables with median + IQR (including minimum and maximum values). Dichotomous and categorical data were reported with *n*/*N* (%). Binary and categorical data were analyzed using Fisher’s exact test (modified version for tables greater than $2 \times 2$) and continuous data with the Kruskal–Wallis rank-sum test. A bilateral significance level of $p < 0.05$ was considered statistically significant. All statistical analyses were calculated using R statistics version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org).

## Results

### Basic characteristics (Table 1)

Twenty experts completed the survey needing a mean time of 12.7 min. Table 1 gives a detailed overview of baseline characteristics and laser equipment used by participating experts. Sixteen (80%) of the participants use simple scissors to cut the laser fiber, two (10%) use special ceramic scissors, and two (10%) do not cut it at all. Most experts (12/20, 60%) do not wear eye protection glasses, and only 30% (6/20) always use protection. X-ray protection glasses and normal correction glasses (both 46%) are preferred over laser protection glasses (7.7%).

### Ureteral UTUCs—URS (Table 2 and Supplementary Table 1)

About half of the experts use their personal laser presetting. Pulse energy during distal ureteral tumor treatment was significantly different among laser sources with 0.9 J, 1 J, and 0.45 J for Ho:YAG, TFL, and pulsed Tm:YAG; respectively ($p = 0.048$). No further differences for distal, middle, and proximal ureteral tumors between the laser sources were found (all $p > 0.05$). Median power for distal, middle, and proximal tumors was 10W, 7W, 10W, 12.5W, and 10W, 9.5W, 10W, 17.5W and 10W, 9.5W, 10W, and 12.5W for Ho:YAG, pulsed Tm:YAG, TFL, and cwTm:YAG, respectively (distal: $p = 0.48$, middle: $p = 0.17$, proximal: $p = 0.74$). There were no differences in maximum power between the lasers (distal: $p = 0.4$, middle: $p = 0.41$, proximal: $p = 0.98$), with Ho:YAG being used with the highest power (up to 24W). Pulse shapes were significantly different for all tumor

**Table 1** Overview of participating experts and laser equipment

| Baseline characteristics | | | |
|---|---|---|---|
| Expert characteristics | | Laser equipment | |
| **Gender** | | **Different laser sources used** | |
| Female | 4/20 (20%) | 1 | 14/20 (70%) |
| Male | 16/20 (80%) | 2 | 5/20 (25%) |
| **Age** | | 3 | 1/20 (5.0%) |
| 30–40 y | 3/20 (15%) | **Laser source** | |
| 40–50 y | 11/20 (55%) | Ho:YAG | 14/20 (70%) |
| > 50 y | 6/20 (30%) | cwTm:YAG | 1/20 (5.0%) |
| **Affiliation** | | TFL | 9/20 (45%) |
| Academic institution | 17/20 (85%) | Pulsed Tm:YAG | 3/20 (15%) |
| State institution | 2/20 (10%) | **Laser generator power output** | |
| Private institution | 2/20 (10%) | < 20 W | 2/20 (10%) |
| **Experience** | | 20–30 W | 1/20 (5.0%) |
| > 20 y | 3/20 (15%) | 30–60 W | 7/20 (35%) |
| 10–20 y | 9/20 (45%) | 60–90 W | 2/20 (10%) |
| 5–10 y | 7/20 (35%) | > 90 W | 8/20 (40%) |
| < 5 y | 1/20 (5.0%) | **Fiber diameter URS [um]** | 245.0 (200.0, 272.0), 150.0, 365.0 |
| **Endoscopic UTUC cases per month** | | **Fiber diameter RIRS [um]** | 200.0 (200.0, 270.0), 150.0, 272.0 |
| < 1 | 5/20 (25%) | **Fiber diameter PCNL [um]** | 365.0 (270.0, 432.5), 200.0, 600.0 |
| 1–5 | 13/20 (65%) | | |
| > 5 | 2/20 (10%) | | |

Numbers are either displayed in *n*/*N* (%) or median (IQR), min, max

*UTUC* upper tract urothelial carcinoma, *Ho:YAG* Holmium–Yttrium–Aluminum–Garnet, *cwTm:YAG* continuous wave thulium–yttrium–aluminum–garnet, *TFL* thulium fiber laser, *URS* ureteroscopy, *RIRS* retrograde intrarenal surgery, *PCNL* percutaneous nephrolithotomy

locations (all $p = 0.005$). Ho:YAG and pulsed Tm:YAG were mainly used in long pulse (86–100%), while TFL was used in short pulse mode (80%). Limitations for distal ureteral UTUC treatment were tumor size (55%, 11/20, median limit of 10 mm, IQR 10–13.75 mm), tumor number (45%, 9/20, median two tumors, IQR 1.5–3), and partially (at least 2/3) or fully circumferential growing tumors (20%, 4/20), which was an extra comment by experts. Limitations for middle and proximal ureteral tumors were similar.

## Pelvic and calyceal UTUCs—RIRS (Table 3 and Supplementary Table 2)

For TFL and cwTm:YAG, users usually use their personal laser presetting. For pulsed Tm:YAG, presettings are not common, and for Ho:YAG, most experts (58–67%) do not apply presettings. There is no difference regarding laser settings between laser sources ($p > 0.05$). Median power is 12W, 9.5W, 10W, 15W, and 11W, 9.5W, 10W, and 15W for Ho:YAG, pulsed Tm:YAG, TFL, and cwTm:YAG, respectively (pelvis: $p = 0.19$, calyx: $p = 0.31$). There were also no differences in maximum power (pelvis: $p = 0.65$, calyx: $p = 0.92$), with TFL used in the highest power settings (up to 40W). Pulse shapes significantly differed for pelvic ($p = 0.048$) and calyceal ($p = 0.005$) tumors. Ho:YAG and pulsed Tm:YAG were mainly used in the long pulse mode (80–100%), compared to TFL in the short pulse mode (75–80%).

Limitations for pelvic UTUC treatment were tumor size (60%, 12/20, median limit of 20 mm, IQR 17.5–20 mm), tumor number (35%, 7/20, median 2.5 tumors, IQR 2–3). Limitations for calyceal UTUC treatment were tumor size (50%, 10/20, median limit of 15 mm, IQR 10–20 mm), tumor number (35%, 7/20, median two tumors, IQR 1.25–2.75). Main additional expert comments included extensive multifocality, not allowing complete treatment (20%, 4/20), and high-grade tumors (10%, 2/20).

## Pelvic and calyceal UTUCs—PCNL (Supplementary Table 3)

Only 35% (7/20) perform percutaneous UTUC treatment. Primary laser is TFL in 57% (4/7), followed by Ho:YAG

**Table 2** Expert settings during laser ureteroscopy (URS) for specific scenarios

| UTUC–URS laser settings | Ho:YAG, $N = 14$ | | | TFL, $N = 8$ | | | Pulsed Tm:YAG, $N = 2$ | | | cwTm:YAG, $N = 2$ | | | $p$ value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Median | IQR | Min, Max | Median | IQR | Min, Max | Median | IQR | Min, Max | Median | IQR | Min, Max | |
| **Distal ureteral tumor** | | | | | | | | | | | | | |
| Energy [J] | **0.9** | 0.75–1.00 | 0.50, 1.00 | **1.00** | 0.90–1.00 | 0.50, 1.00 | **0.45** | 0.43–0.48 | 0.40, 0.50 | NA | NA | NA | **0.048** |
| Frequency [Hz] | **10.00** | 10.00–11.25 | 8.00, 20.00 | **10.00** | 10.00–10.00 | 10.00, 15.00 | **15.00** | 12.50–17.50 | 10.00, 20.00 | NA | NA | NA | 0.54 |
| Power [W] | **10.00** | 7.20–10.00 | 6.00, 16.00 | **10.00** | 9.00–10.00 | 5.00, 15.00 | **7.00** | 5.50–8.50 | 4.00, 10.00 | **12.50** | 11.25–13.75 | 10.00, 15.00 | 0.48 |
| Max. energy [J] | **1.00** | 1.00–1.00 | 0.80, 1.50 | **1.00** | 1.00–1.00 | 0.80, 2.00 | **0.80** | 0.80–0.80 | 0.80, 0.80 | NA | NA | NA | 0.24 |
| Max. frequency [Hz] | **15.00** | 10.00–20.00 | 10.00, 20.00 | **10.00** | 10.00–12.50 | 10.00, 20.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | NA | NA | NA | 0.17 |
| Max. power [W] | **11.00** | 10.00–15.00 | 8.00, 24.00 | **10.00** | 10.00–16.00 | 10.00, 20.00 | **12.00** | 12.00–12.00 | 12.00, 12.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | 0.4 |
| **Middle ureteral tumor** | | | | | | | | | | | | | |
| Energy [J] | **0.90** | 0.80–1.00 | 0.50, 1.00 | **1.00** | 0.90–1.00 | 0.50, 1.00 | **0.55** | 0.53–0.58 | 0.50, 0.60 | NA | NA | NA | 0.11 |
| Frequency [Hz] | **10.00** | 10.00–15.00 | 8.00, 20.00 | **10.00** | 10.00–10.00 | 10.00, 15.00 | **17.50** | 16.25–18.75 | 15.00, 20.00 | NA | NA | NA | 0.12 |
| Power [W] | **10.00** | 8.00–10.50 | 6.00, 16.00 | **10.00** | 9.00–10.00 | 5.00–15.00 | **9.50** | 9.25–9.75 | 9.00, 10.00 | **17.50** | 16.25–18.75 | 15.00, 20.00 | 0.17 |
| Max. energy [J] | **1.00** | 1.00–1.00 | 1.00, 1.50 | **1.00** | 1.00–1.00 | 0.80, 2.00 | **0.80** | 0.80–0.80 | 0.80, 0.80 | NA | NA | NA | 0.13 |
| Max. frequency [Hz] | **15.00** | 10.00–20.00 | 10.00, 20.00 | **10.00** | 10.00–12.50 | 10.00, 20.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | NA | NA | NA | 0.24 |
| Max. power [W] | **10.00** | 10.00–15.00 | 8.00, 24.00 | **10.00** | 10.00–16.00 | 10.00, 20.00 | **12.00** | 12.00–12.00 | 12.00, 12.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | 0.41 |
| **Proximal ureteral tumor** | | | | | | | | | | | | | |
| Energy [J] | **0.90** | 0.80–1.00 | 0.50, 1.00 | **1.00** | 0.90–1.00 | 0.50, 1.00 | **0.55** | 0.53–0.58 | 0.50, 0.60 | NA | NA | NA | 0.11 |
| Frequency [Hz] | **10.00** | 9.50–15.00 | 5.00, 20.00 | **10.00** | 10.00–10.00 | 10.00, 15.00 | **17.50** | 16.25–18.75 | 15.00, 20.00 | NA | NA | NA | 0.15 |
| Power [W] | **10.00** | 8.00–10.50 | 3.00, 16.00 | **10.00** | 9.00–11.25 | 5.00, 20.00 | **9.50** | 9.25–9.75 | 9.00, 10.00 | **12.50** | 11.25–13.75 | 10.00, 15.00 | 0.74 |
| Max. energy [J] | **1.00** | 1.00–1.00 | 1.00, 1.50 | **1.00** | 1.00–1.00 | 0.80, 2.00 | **0.80** | 0.80–0.80 | 0.80, 0.80 | NA | NA | NA | 0.12 |
| Max. frequency [Hz] | **15.00** | 10.00–20.00 | 10.00, 20.00 | **10.00** | 10.00–12.50 | 10.00, 20.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | NA | NA | NA | 0.2 |
| Max. power [W] | **12.50** | 10.00–15.00 | 8.00, 24.00 | **10.00** | 10.00–16.00 | 10.00, 20.00 | **12.00** | 12.00–12.00 | 12.00, 12.00 | **15.00** | 12.50–17.50 | 10.00, 20.00 | 0.98 |

Median (IQR) and min, max values are given. Significant $p$ values ($p < 0.05$) are highlighted in bold

*Ho:YAG* Holmium–Yttrium–Aluminum–Garnet, *TFL* thulium fiber laser, *cwTm:YAG* continuous wave thulium–yttrium–aluminum–garnet, pulsed Tm:YAG

**Table 3** Expert settings during laser retrograde intrarenal surgery (RIRS) for specific scenarios

| UTUC–RIRS laser settings | Ho:YAG, $N=12$ | | | TFL, $N=9$ | | | Pulsed Tm:YAG, $N=2$ | | | cwTm:YAG, $N=1$ | | | $p$ value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Median | IQR | Min, Max | Median | IQR | Min, Max | Median | IQR | Min, Max | Median | IQR | Min, Max | |
| **Pelvic tumor** | | | | | | | | | | | | | |
| Energy [J] | **1.00** | 1.00–1.00 | 0.50, 1.50 | **1.00** | 0.80–1.00 | 0.60, 2.00 | **0.55** | 0.53–0.58 | 0.50, 0.60 | NA | NA | NA | 0.085 |
| Frequency [Hz] | **12.00** | 10.00–15.00 | 10.00, 25.00 | **10.00** | 10.00–10.00 | 10.00–20.00 | **17.50** | 16.25–18.75 | 15.00, 20.00 | NA | NA | NA | 0.11 |
| Power [W] | **12.00** | 10.00–14.25 | 10.00, 25.00 | **10.00** | 10.00–10.00 | 6.00, 30.00 | **9.50** | 9.25–9.75 | 9.00, 10.00 | **15.00** | 15.00–15.00 | 15.00, 15.00 | 0.19 |
| Max. energy [J] | **1.00** | 1.00–1.28 | 1.00, 2.00 | **1.00** | 1.00–1.25 | 0.80, 2.00 | **0.80** | 0.80–0.80 | 0.80, 0.80 | NA | NA | NA | 0.2 |
| Max. frequency [Hz] | **17.50** | 15.00–22.50 | 10.00, 30.00 | **15.00** | 10.00–20.00 | 10.00, 20.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | NA | NA | NA | 0.45 |
| Max. power [W] | **15.00** | 15.00–25.50 | 10.00, 30.00 | **18.00** | 10.00–20.00 | 10.00, 40.00 | **16.00** | 16.00–16.00 | 16.00, 16.00 | **30.00** | 30.00–30.00 | 30.00, 30.00 | 0.65 |
| **Calyceal tumor** | | | | | | | | | | | | | |
| Energy [J] | **1.00** | 1.00–1.00 | 0.50, 1.50 | **1.00** | 1.00–1.00 | 0.60, 2.00 | **0.55** | 0.53–0.58 | 0.50, 0.60 | NA | NA | NA | 0.077 |
| Frequency [Hz] | **12.50** | 10.00–15.00 | 10.00, 25.00 | **10.00** | 10.00–15.00 | 10.00, 15.00 | **17.50** | 16.25–18.75 | 15.00, 20.00 | NA | NA | NA | 0.16 |
| Power [W] | **11.00** | 10.00–15.00 | 10.00, 25.00 | **10.00** | 10.00–15.00 | 6.00, 30.00 | **9.50** | 9.25–9.75 | 9.00, 10.00 | **15.00** | 15.00–15.00 | 15.00, 15.00 | 0.31 |
| Max. energy [J] | **1.00** | 1.00–1.28 | 1.00, 2.00 | **1.00** | 1.00–1.25 | 1.00, 2.00 | **0.80** | 0.80–0.80 | 0.80, 0.80 | NA | NA | NA | 0.15 |
| Max. frequency [Hz] | **20.00** | 15.00–22.50 | 10.00, 30.00 | **15.00** | 10.00–20.00 | 10.00, 20.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | NA | NA | NA | 0.28 |
| Max. power [W] | **17.50** | 15.00–25.50 | 10.00, 30.00 | **17.50** | 13.75–20.00 | 10.00, 40.00 | **16.00** | 16.00–16.00 | 16.00, 16.00 | **20.00** | 20.00–20.00 | 20.00, 20.00 | 0.92 |

Median (IQR) and min, max values are given. Significant $p$ values ($p < 0.05$) are highlighted in bold

*Ho:YAG* Holmium–Yttrium–Aluminum–Garnet, *TFL* thulium fiber laser, *cwTm:YAG* continuous wave thulium–yttrium–aluminum–garnet, pulsed Tm:YAG in 43% (3/7) ($p = 1.0$). Personal laser presettings are usually not applied (75%), and there were no significant differences between laser sources (all $p > 0.05$). Median power for pelvic and calyceal tumors was 11W, 10W, and 8W, 8W for Ho:YAG and TFL, respectively (pelvis: $p = 0.46$, calyx: $p = 0.44$). The maximum power used for pelvic ($p = 0.62$) and calyceal ($p = 0.62$) tumors was 40W and 20W for both lasers. Pulse shapes did not differ significantly ($p = 0.33$); however, only limited observations were available ($n = 4$). Ho:YAG was used in long pulse (100%) and TFL in medium and short pulses (each 50%).

Limitations for pelvic percutaneous UTUC treatment are tumor size (71%, 5/7, median limit of 20 mm, IQR 17.5–22.5 mm), tumor number (57%, 4/7, median two tumors, IQR 1.5–3.5), and skin-to-tumor distance (14%, 1/7, median 15 cm). Calyceal percutaneous UTUC treatment limitations are tumor size (71%, 5/7, median limit of 20 mm, IQR 18.75–22.5 mm) and tumor number (43%, 3/7, median two tumors, IQR 1.5–2.5).

### Technical aspects, limits, and preventive measures (Supplementary Table 4)

During RIRS, most experts (68%) fix the laser fiber in the flexible scope, and 16% never fix it. Most experts (63%) believe that thermal injury can cause complications. The median power safety limit during URS and RIRS is 10W, 20W, and 20W for ureteral, pelvic, and calyceal UTUC treatment. The median power safety limit for percutaneous treatment is 27.5W for pelvic and 22.5W for calyceal tumors. To reduce the risk of temperature-induced damage during ureteral tumor treatment, experts use laser power regulations (58%, 11/19, median limit 10 W, IQR 10–15 W), intermittent laser activation (42%, 8/19), intelligent pump devices (42%, 8/19), and chilled irrigation (26%, 5/19). For RIRS tumor treatment, preventive measures are laser power regulations (58%, 11/19, median limit 20W, IQR 20–24.5W), intelligent pump devices (47%, 9/19), ureteral access sheaths (UASs) (47%, 9/19, Ch10/12–50%, Ch11/13–25%), and chilled irrigation (32%, 6/19). For percutaneous tumor treatment, measures were laser power regulations (26%, 5/19, median limit 30W, IQR 20-35W), increasing inflow (26%, 5/19), increasing shaft diameter and chilled irrigation (each 21%, 4/19), and flow dynamics (11%, 2/19).

### Subjective assessment of laser types by experts (Supplementary Table 5)

Advantages of Ho:YAG included versatility, effective ablation, and less risk of ureteral stenosis due to less carbonization/charring and damage to sub-epithelial tissue. Disadvantages included its hemostatic features and less control (risk of perforation). For Tm:YAG, its advantages were its excellent hemostatic features, precise dissection, and speed; disadvantages included tissue charring. The advantages of TFL were its excellent hemostasis, precision due to narrow penetration depth, no carbonization when used with low powers, small fiber size, and good ablation, while temperature generation was a limitation.

### Recommendations on laser settings and preventive measures (Table 4)

We identified general (laser generators, power output, and fiber diameter) and common (median and maximum power, and median and maximum pulse energy) laser settings, and strategies to reduce complications (dichotomous and categorical responses). *Common* was defined as ≥ 75% of expert answers fitting a statement.

## Discussion

Due to the limited available literature focusing on detailed laser settings during UTUC treatment, this study aimed to collect expert information about laser settings used for endoscopic and percutaneous UTUC treatment. We also examined laser complication prevention measures. We specifically focused on URS, RIRS, and PCNL treatment, representing the main treatment strategies of kidney-sparing surgery. We finally provided recommendations covering main, general, and laser settings during various clinical scenarios to help endourologists optimize treatment outcomes.

There are several important findings in this work. First, Ho:YAG lasers still represent the main laser source, with 70% of experts using it, followed by TFL in 45%, pulsed (15%), and cw (5%) Tm:YAG. Possible explanations for this finding may be related to the physical characteristics of different lasers and their behavior on upper tract urothelial tissue. Ho:YAG incisions are deeper and irregular (saccular) compared to the narrower, homogenous, and tubular-like cwTm:YAG incisions, the coniform, rounded apex quasi-continuous wave (qcw)-TFL incisions [13, 14], and the Ho:YAG-like incisions of super-pulsed TFL [14]. Broad coagulation zones are a typical feature of cwTm:YAG and qcwTFL, while they are absent with Ho:YAG, and much less pronounced with pulsed and super-pulsed TFL lasers [13, 15, 16]. When comparing the effect on tissue with solid-state lasers, researchers demonstrated a more controllable behavior with the pulsed Tm:YAG compared to cwTm:YAG and Ho:YAG, which was the least controllable laser at low powers [17]. Furthermore, researchers demonstrated minimal differences in vaporization volume, incision depth, and thermomechanical damage zone between qcw and super-pulsed

**Table 4** Expert recommendations and guide map for laser settings during endoscopic UTUC treatment

Guide map and recommendations for endourologists

| | Statement | | |
|---|---|---|---|
| Domain | Power | Pulse energy | Frequency |
| URS–Ho:YAG (std.) | ≤ 10W (distal); ≤ 10.5W (middle + proximal) | ≤ 1 J (all locations) | ≤ 11.25 Hz (distal); ≤ 15 Hz (middle + proximal) |
| URS–Ho:YAG (max.) | ≤ 15W (all locations) | ≤ 1 J (all locations) | ≤ 20 Hz (all locations) |
| URS–TFL (std.) | ≤ 10W (distal + middle) ≤ 11.25W (proximal) | ≤ 1 J (all locations) | ≤ 10 Hz (all locations) |
| URS–TFL (max.) | ≤ 16W (all locations) | ≤ 1 J (all locations) | ≤ 12.5 Hz (all locations) |
| RIRS–Ho:YAG (std.) | ≤ 14.25W (pelvis) ≤ 15W (calyces) | ≤ 1 J (all locations) | ≤ 15 Hz (all locations) |
| RIRS–Ho:YAG (max.) | ≤ 25.5W (all locations) | ≤ 1.28 J (all locations) | ≤ 22.5 Hz (all locations) |
| RIRS–TFL (std.) | ≤ 10W (pelvis) ≤ 15W (calyces) | ≤ 1 J (all locations) | ≤ 10 Hz (pelvis); ≤ 15 Hz (calyces) |
| RIRS–TFL (max.) | ≤ 20W (all locations) | ≤ 1.25 J (all locations) | ≤ 20 Hz (all locations) |
| Fiber diameter | URS ≤ 272um, RIRS ≤ 270um, PCNL ≤ 433um | | |
| Fiber | Simple scissors seem to be efficient for cutting the fiber tip | | |
| Pulse shape | Ho:YAG: long pulse (URS, RIRS, PCNL) | | |
| Pulse shape | TFL: short pulse (URS, RIRS) | | |
| URS–safety limit | all locations ≤ 15W | | |
| RIRS–safety limit | all locations ≤ 25W | | |
| PCNL–safety limit | pelvis ≤ 36.25W; calyces ≤ 35W | | |

Survey answers were analyzed, and common settings, limits and ranges were identified. Common was defined as ≥ 75% of experts with at least $n = 5$ survey answers for the regarding question and laser source fitting a statement. Standard (std.) and maximum (max.) laser settings are given for Ho:YAG and TFL only due to the limited responses for other laser sources

*Ho:YAG* Holmium–Yttrium–Aluminum–Garnet, *TFL* thulium fiber laser

TFL. However, qcwTFL produced a significantly larger coagulation zone with more pronounced carbonization than super-pulsed TFL [18]. Of note, TFL lasers are utilized with small caliber laser fibers, offering improved irrigation and scope flexion during RIRS.

Second, apart from differences for pulse energies during distal ureteral tumor treatment, we did not find significant differences in laser settings among different laser sources. Nevertheless, we reported a high heterogeneity in maximum power settings between lasers. Personal expert preferences could play a role in this phenomenon.

Third, percutaneous treatment was only performed by 35% of the experts, reflecting its generally low application. Percutaneous treatment of UTUC has proven efficient in selected, mainly low-grade tumors [19]. However, in recent years, research interest has declined. According to the EAU guidelines on UTUC, PCNL treatment should be reserved for low-risk pelvic or calyceal system tumors, which might be inaccessible with RIRS [1]. An additional drawback of percutaneous access is the risk of tumor seeding [20], necessitating a close and costly follow-up with repeated interventions. Early second-look ureteroscopy within 6–8 weeks was shown to predict further recurrence and risk of subsequent RNU [21].

Moreover, we observed a significant difference between pulse shapes among different lasers, with Ho:YAG preferably used in long and TFL in short pulse mode. However, no Ho:YAG pulse modulations like Moses ™ or Virtual Basket™ were applied. Despite recent evidence on the beneficial effects of Ho:YAG pulse modulation in surgery speed and hemostasis during endoscopic enucleation of the prostate (EEP) [22, 23], no evidence exists regarding UTUC treatment. On the other hand, although TFL can be operated in qcw mode, most experts apply short pulses with frequencies around 10–15 Hz. In theory, higher frequencies combined with long pulse durations or qcw mode would improve cutting and result in better hemostasis, yet with pronounced carbonization [16, 18, 24]. According to Proietti et al., the super-pulsed TFL setting combines the beneficial aspects of cwTm:YAG and Ho:YAG, reducing carbonization effects while avoiding a high mechanical impact [10].

Further, only 47% of experts use UASs during UTUC treatment with RIRS, which contradicts the > 80% of experts using UAS during laser lithotripsy (internal data of a different survey). Despite the relevance of bladder recurrences with diagnostic URS/RIRS [25] and ureteral catheterization [26], UASs seem to have a protective effect [27]. Additionally, UASs can prevent complications induced by high intrarenal pressures, which can cause tumor seeding [28]. Finally, most experts (63%) believe thermal laser injury may cause complications during UTUC treatment [16]. All used at least one preventive measure during URS/RIRS, like power regulations (10W for URS and 20W for RIRS), intermittent laser activation (URS), and UASs combined with pump systems (RIRS), which have proved to be beneficial [29].

'Due to the limited number of experts included in the project and the absence of objective criteria for expert selection, the findings of our project might not be generalizable as a 'modus operand' to the entire endourological community and must be interpreted cautiously.' However, from a methodological point of view, we think that gathering the opinions of experts with vast experience in contemporary UTUC treatment represents a legitimate approach to collecting suitable evidence. This effort must be particularly emphasized in the context of a generally low application of endoscopic UTUC treatment and high costs related to repeated interventions [30].

Notably, 32% of experts included in this project did not choose the laser equipment they were working with, but it was provided by the hospital/their institution. This is a crucial point because laser parameters are directly dependent on the possible setting range of the laser generator/laser equipment. Thus, a certain pre-selection bias can be assumed.

Further, we did not include information about scanning speed and distance between the fiber tip and the surgical plane, which are important variables when predicting the effect of lasers on tissue, as their evaluation is out of the range of a survey study. However, we tried to cover important topics like complication prevention measures and subjective assessments of the different laser types. Despite the initial plan of a Delphi consensus, we decided against more survey rounds after the initial analysis of responses. Reasons for this decision included the adequate data and the not-justifiable expert efforts. Instead, we considered ≥ 75% expert agreement as significant for our recommendations. Hence, from our perspective—and given the present methodology—it is neither possible nor scientifically justifiable to define exact 'must-not-exceed' or 'need to be' settings for several laser variables (such as power and pulse energy).

## Conclusion

Despite applying various lasers, Ho:YAG still represents the mainstay of laser UTUC treatment for most experts. However, TFL is the most promising alternative combining the beneficial characteristics of both cwTm:YAG and Ho:YAG. Laser settings do not vary greatly, yet further research with novel lasers is necessary to define the optimal approach. Novel small caliber and more flexible scopes permit better access to difficult tumor locations and better irrigation, which leads to further applicability of minimally invasive UTUC treatment as an oncologically safe option for appropriately selected patients, yet recurrences are common.

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**Data availability** The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

### Declarations

**Conflict of interest** Gernot Ortner certifies that all conflicts of interest, including specific financial interests and relationships and affiliations relevant to the subject matter or materials discussed in the manuscript (e.g., employment/affiliation, grants or funding, consultancies, honoraria, stock ownership or options, expert testimony, royalties, or patents filed, received, or pending), are the following: None. Thomas Tailly: Consultant Boston Scientific, Cook Medical, Dornier, Storz. Guido Kamphuis: Advisory board: Boston Scientific, Olympus, Honoraria: Alnylam, Boston Scientific, Coloplast Porgès, Olympus. Amelia Pietropaolo: Consultant Boston Scientific, Ambu, Pusen. Panagiotis Kallidonis: Consultant Cook Medical, EMS. Mordechai Duvdevani: Consultant Boston Scientific. Udo Nagele: Consultant Baxter, Boston Scientific, Optimed, Storz medical, B + K. Laurian Dragos: Consultant EMS, Boston Scientific, Ambu. Silvia Proietti: Consultant Boston Scientific. Joyce Baard: Consultant Coloplast, Boston Scientific, Olympus, Urogen. Øyvind Ulvik: Lectures Olympus.

**Research involving human participants and/or animals** This review does not involve human participants and/or animals.

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