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ORIGINAL ARTICLE

Is loss of power output due to laser fiber degradation still an issue during prostate vaporization using the 180 W GreenLight XPS laser?

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Abstract

Purpose To investigate whether heat-induced fiber degradation and loss of power output, which occurred during GreenLight laser vaporization (LV) of the prostate using the first- and second-generation 80 and 120 W laser, are still an issue during LV using the upgraded third generation 180 W GreenLight XPS™ laser.

Methods Laser beam power output of 53 laser fibers was measured at baseline and after every 25 kJ of delivered energy during routine 180 W GreenLight XPS™ LV in 47 patients with prostatic bladder outflow obstruction. After the procedures, the fiber tips were microscopically examined.

Results The median applied energy per patient was 178 kJ [interquartile range (IQR): 106–247]. Loss of power output during the procedure was detectable in all fibers. After the application of 25, 150, and 250 kJ, the median power output decreased to 77% (IQR 59–87), 57% (IQR 32–71), and 51% (IQR 37–64) of the baseline value. Nine fibers (17%) remained on a relatively high power output level (> 80% of the initial output), while 13 fibers (25%) showed an end-of-procedure power output of less than 20%. Microscopy of the fiber tip revealed mild-to-moderate overall degradation and increasing degradation with higher energy delivered.

Conclusion Despite changes in fiber design, heat-induced fiber damage and loss of power output remain an issue during 180 W GreenLight XPS™ LV. Whether modifications of the surgical technique can prevent impairment of fiber performance needs to be further evaluated.

Keywords Prostatic hyperplasia · Transurethral resection of prostate · Lasers · Disposable equipment · Equipment failure analysis · Laser fiber laser prostatectomy

Introduction

The GreenLight™ laser vaporization (LV) procedure is an established alternative to conventional transurethral resection of the prostate (TURP) for patients with symptomatic bladder outlet obstruction secondary to prostate enlargement [1–5]. Low intra- and perioperative morbidity in combination with functional short-term results comparable to those after TURP has constantly been reported [6–8].

The laser system underwent several modifications since its first clinical introduction [9–11]. These modifications were necessary because high re-treatment rates due to insufficient tissue ablation were reported after LV using the first-generation 80 W system [8, 12, 13]. Low output power of the system in combination with additional loss of power output caused by fiber degradation during the procedure was identified as the main reason for its limited effectiveness [14–18].

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The second-generation laser was characterized by a higher maximum output power of 120 W [11]. The power was raised to improve tissue ablation during the procedure. However, high output power is also a risk factor for fiber degradation [14, 15, 19]. Although modifications of the laser fiber were announced for the 120 W system, heat-induced degradation of the fiber tip associated with a significant reduction of the initial power output of 50% was still detectable during the procedure [14].

The modifications of the latest-generation XPS™ laser further addressed the issues of limited effectiveness and fiber degradation [11, 14, 18]. The maximum power output was raised to 180 W, and a novel laser fiber with a larger emission window, active fiber cooling (MoXy™ fiber system), and an integrated heat-sensor at the fiber tip (FiberLife™) were introduced.

A small-scale, company-sponsored investigation revealed improved fiber performance and constant power output during 180 W LV of the prostate [20]. However, these results have never been validated in an independent large-scale study. The aim of the present study was to investigate whether degradation of the laser fiber and a decrease of power output occur during routine 180 W GreenLight XPS™ LV of the prostate.

Materials and methods

This prospective study was performed with a consecutive series of patients undergoing routine GreenLight XPS™ LV of the prostate for prostatic bladder outlet obstruction in a tertiary care academic center with longstanding expertise in GreenLight LV. GreenLight LV is our standard procedure for patients presenting with anticoagulation or platelet inhibition medication, but is also performed in patients who wish to undergo the procedure. The local ethics committee approved the study protocol. All patients provided written informed consent.

All LVs were performed using the AMS 180 W GreenLight XPS™ laser with Moxy™ fibers (Boston Scientific, Marlborough, USA). The procedure was performed as described previously using a 24F continuous-flow Iglesias laser resectoscope (Karl Storz AG Tuttlingen, Germany) [15, 21]. Continuous cooling of the fiber was performed during the entire procedure with normal saline according to the company's guidelines. The power setting of the laser was at the discretion of the responsible surgeon. The procedure was usually terminated with the appearance of a TURP-like cavity [15].

For the power output measurements, a custom-made fiber holder was used to guarantee a steady fiber position for each measurement series (Fig. 1a). The fiber tip was placed into sterile saline and the laser was shortly activated with ongoing irrigation for fiber cooling. The emitted laser beam was directed trough a lens and attenuated by two beam samplers (Fig. 1b), as described previously [14]. Thus, 0.49% of the emitted power was finally measured using an optical PM121 power meter (Thorlabs, Dachau, Germany).

Laser beam power measured prior to the start of each operation was used as baseline value (100%). Further measurements were performed in intervals of 25 kJ until termination of the procedure. The relative decrease of power output during each procedure was calculated as percentage of the respective baseline value.

Surgeons, blinded to the results of the performed measurements, were asked to report whether and when they perceived a marked decrease of the ablative efficiency during the procedure. Furthermore, they estimated the end-of-procedure performance of the respective fibers [perfect (> 80% of the initial performance), moderate (40–80%), and poor performance (< 40%)]. These subjective estimates were compared to the actual measurements.

In addition, the laser fiber tips were microscopically assessed after each procedure and the degree of degradation was rated to be either mild, moderate, severe, or complete, as described previously [14].

A subgroup analysis was performed to assess differences in intraoperative parameters between patients which experienced a dramatic loss of power output (< 20%) and all other patients.

Strict non-contact LV was performed in vitro to investigate power output changes during LV without any fiber-tissue contact as described before [15]. These measurements were performed according to the measurements during in vivo LV.

Clinical outcome was assessed using the International Prostate Symptom Score (IPSS) with Quality of Life (QoL) domain, uroflowmetry with residual volume measurements, and prostate-specific antigen values. These parameters were assessed preoperatively as well as 6 weeks and 6 months after the procedure.

Continuous variables are presented as median [interquartile range (IQR)] and categorical variables as number (percent). Statistical analyses were performed using Microsoft Excel 2017 (Microsoft Corporation, Redmond, Washington, USA) and SPSS® Version 22 (IBM, Armonk, New York, USA). The Mann–Whitney *U* test was used for the subgroup analysis. The Wilcoxon signed-rank test was used to assess changes in outcome parameters from baseline. A p value < 0.05 (two sided) was considered statistically significant.

Results

A total of 53 laser fibers were investigated during LV in 47 patients. Patients' baseline characteristics are summarized in Table 1A. Seven different surgeons performed the 47

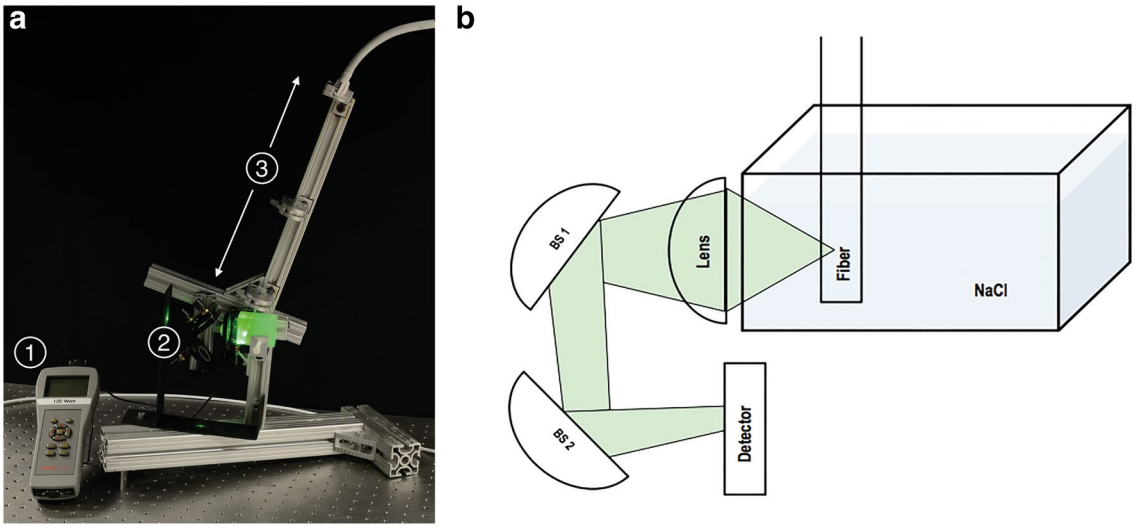

Fig. 1 **a** The fiber was fixed using a snap fit holder system. The measurement device (1) is connected to the optical power meter and displays the average laser beam energy for each measurement. The laser measurement was performed under sterile saline (2). A fiber holder (3) was used to guarantee steady laser beam position for each measurement. **b** Measurement setup with green laser beam course. The fiber tip was placed in sterile saline and the laser was activated under continuous water cooling during the measurement. After its emission from the fiber the laser beam was attenuated to allow precise measurements [lens and two beam sampler (BS)]

procedures. Five experienced surgeons (> 50 previous LVs) performed 37 (79%) and two senior residents performed ten (21%) procedures under the supervision of an experienced surgeon. All procedures were successfully completed without intraoperative complications.

Intraoperative results are summarized in Table 1B. Forty-one procedures (87%) were completed using only one fiber. A second laser fiber was used in six patients (13%) due to premature fiber degradation and markedly impaired tissue ablation during the procedure (for details see supplemental table). The median applied laser energy per patient was 178 kJ (IQR: 106–247).

Figure 2 illustrates the median decrease of power output during the procedure of all investigated fibers. After the application of 25 kJ, the median power output had decreased to 77% (59–87) of the baseline value. Subsequently, a constant but overall moderate decrease of power output was detectable. After the application of 150 and 250 kJ, the median power output was 57% (32–71) and 51% (37–64), respectively. For the ten fibers that delivered 250–400 kJ, no further decrease of power output was detectable. The power output of 9 fibers (17%) remained rather high during the entire procedure (> 80% of the initial output), but 13 fibers (25%) showed a power output of less than 20% at the end of the procedure.

In all investigated fibers, degradation of the emission window was microscopically detectable at the end of the procedure. Degradation increased simultaneously with increasing energy applied (Fig. 2b). Overall, fiber degradation was only moderate. Complete fiber-tip destruction was detectable in two fibers (4%).

The power output estimates of the surgeons were available for 50 of 53 investigated fibers. The median power output estimated by the surgeons at the end of the procedure was 80% (IQR 40–80). Thirty of these fibers (60%) were rated to still have perfect performance at the end of the procedures (≥ 80% of initial performance). Nine fibers (18%) were rated to have a moderate performance (40–80%) and 11 fibers (22%) a poor performance (≤ 40%). Five of the six fibers that were replaced during the procedure due to an estimated poor performance were in the group of fibers with a measured overall decrease of less than 20%. The measured median end-of-procedure power output of the fibers rated to have perfect, moderate, and poor performance was 64% (44–80), 55% (50–60), and 10% (4–22), respectively (supplemental figure).

Subgroup analysis revealed that the patients treated with the 13 fibers with a dramatic decrease of power output had a significantly longer operative time [90 min (78–100) vs. 65 min (45–78); $p = 0.001$], laser lasing time [45 min (38–55) vs. 34 min (21–45); $p = 0.03$], and a higher total laser energy applied [237 kJ (205–337) vs. 163 kJ (94–220); $p = 0.009$] compared to all other patients who had a less dramatic decrease of power output.

The fiber used for non-contact in vitro vaporization showed a stable course of power output without a relevant decrease during the procedure. The decrease of power output was 0 and 11% after the application of 150 and 250 kJ,

Table 1 Baseline characteristics (A) and intraoperative parameters (B)

A	
Number of patients	47
Age (years)	73 (66–79)
Prostate volume (ml)	40 (32–50)
PSA (ng/ml)	2.0 (1.0–6.04)
BPH/PCA (*n*)	44/3 (94/6)
Indwelling catheter (*n*)	8 (17%)
IPSS	17 (11–20)
Qol	3 (1–5)
Qmax (ml/s)	10 (7–14)
Residual volume (ml)	79 (48–150)
Platelet aggregation inhibitor medication (*n*)	27 (57%)
Anticoagulation medication (*n*)	8 (17%)
B	
No. of fibers (*n*)	53
Procedures using 1 fiber	41 (87%)
Procedures using 2 fibers	6 (13%)
Operative time (min)*	70 (50–90)
Applied energy (kJ)	
Per fiber	175 (103–244)
Per patient	178 (106–247)

Data are presented as median (interquartile range) or number (percent). The *p* values indicate differences in the outcome compared to the respective baseline values

PSA prostate-specific antigen, *BPH* benign prostatic hyperplasia, *PCA* prostate cancer, *IPSS* International prostate symptom score, *Qol* quality of life, *Qmax* maximum flow rate, *kJ* kilojoule

*Includes the time for measurements [approximately 2 min for each measurement (at baseline and after every 25 kJ applied)]

respectively. Fiber degradation was mild at the tip of this fiber (Fig. 2b).

Postoperative complications such as cardiovascular events or clot retention requiring re-operation or blood transfusions did not occur after the procedures. Median duration of postoperative catheterization was 3 days (IQR 3–3). Eight patients (17%) were re-catheterized due to postoperative urinary retention and six patients (13%) were discharged with their catheter in place. Subsequently, all of these patients had their catheters removed in our outpatient clinic.

The postoperative outcome parameters after 6 weeks and 6 months are summarized in Table 2. All outcome parameters improved significantly after 6 weeks and 6 months, when compared to baseline.

Discussion

This is the first comprehensive non-industry-sponsored investigation of power output changes during routine 180 W GreenLight XPS™ LV of the prostate. The study revealed structural changes of the fiber tip associated with a significant decrease in power output in most of the investigated fibers. The median decrease of power output of almost 50% indicates that the implemented changes in fiber design cannot fully prevent fiber degradation and loss of power output. In our study, only 17% of the investigated fibers showed an optimal course with less than 20% decrease in power output during the procedure. In most of the fibers with a massive decrease (> 80%) in power output, the surgeons were able to identify the poor fiber performance and sometimes even decided to change the fiber during the procedure.

Our results are different to the results reported by Brunken and colleagues who also performed power output measurements during 180 W GreenLight XPS™ LV [20]. In contrast to our findings, they observed no relevant decrease in power output at all. Fiber malfunctions were not observed, and the median power output at the end of the procedure was 97% of the baseline value. There are relevant differences between their study and our study, which need to be taken into consideration when interpreting the different results: In our study, several surgeons with different levels of experience performed the procedure. Furthermore, the techniques used for vaporization might have been different in the two studies. The study by Brunken et al. is a small-scale company-sponsored investigation which only included ten

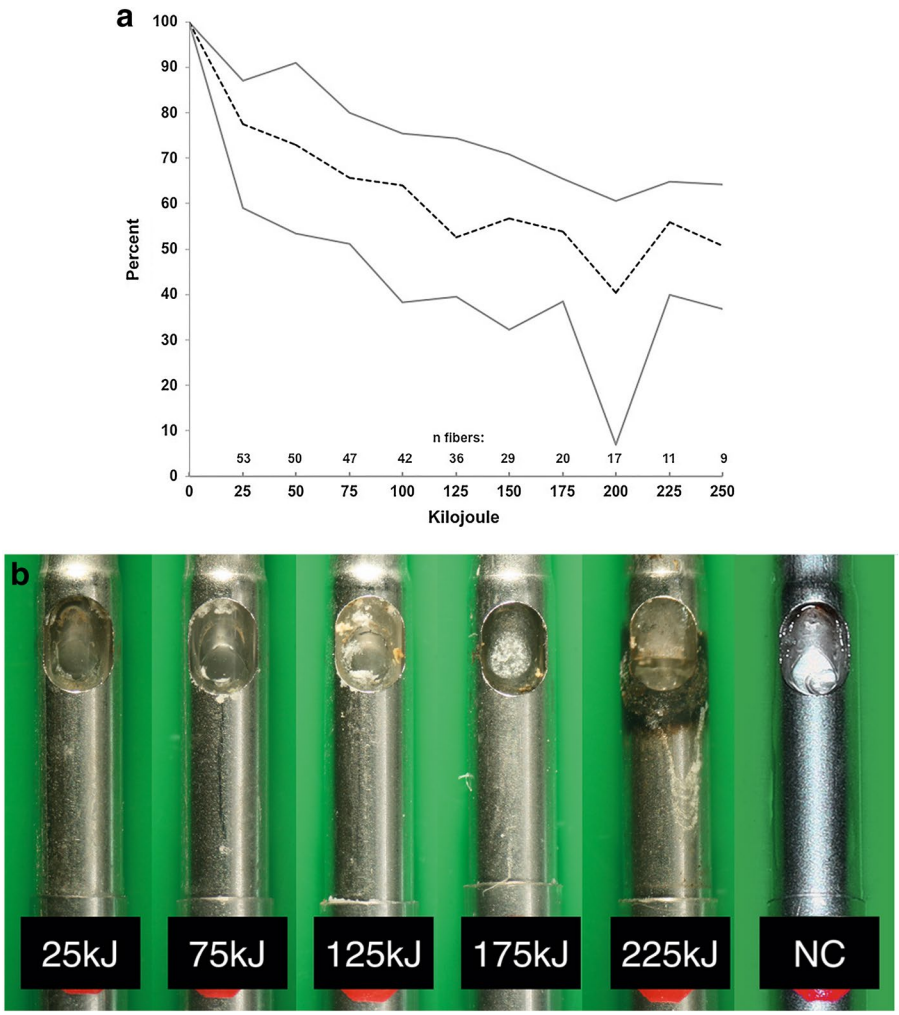

Fig. 2 **a** Median decrease (dashed line) and IQR (gray lines) of all 53 investigated fibers up to 250 kJ. Most fibers showed a mild but continuous decrease of power output during the procedure. Upper gray curve indicates upper quartile and lower gray curve indicates lower quartile. **b** Examples of different fiber tips after the application of 25–225 kJ and non-contact (NC) in vitro vaporization. Fiber alterations slightly increased with total energy applied. Only slight degradation was detected at emission window after strict NC in vitro vaporization

patients. Their measurement setup is only scarcely described and apart from preoperative prostate volumes no clinical baseline or follow-up data are reported. Furthermore, two of the authors, including the first author reported a relevant conflict of interest.

The decrease in power output associated with structural changes of the laser fiber is in line with previous findings of our group and others [14, 15, 18]. However, particularly for the first-generation 80 W laser, these changes were more pronounced compared to the successor models. The final power output was only 20% after 80 W LV. In contrast, the

Table 2 Postoperative outcome

	Baseline	6 weeks	6 months
No. of patients	47	41	37
IPSS	17 (11–20)	4 (2–8) $p<0.001$	3.5 (1–7) $p<0.001$
QoL	3 (1–5)	1 (1–2) $p=0.001$	1 (0–2) $p<0.001$
Qmax (ml/s)	10 (7–14)	19 (13–28) $p=0.005$	15 (12–24) $p=0.002$
Residual volume (ml)	79 (48–150)	10 (0–40) $p=0.002$	20 (0–50) $p<0.001$
PSA (ng/ml)	2.0 (1.00–6.04)	1.93 (0.87–4.16) $p=0.024$	1.59 (0.59–4.63) $p<0.001$

Data are presented as median (interquartile range) or number (percent). The *p* values indicate differences in the outcome compared to the respective baseline values

PSA prostate-specific antigen, *IPSS* International prostate symptom score, *Qol* quality of life, *Qmax* maximum flow rate

end-of procedure output was still around 50% after 120 and 180 W XPS™ LV. However, it is important to mention that due to the lack of patients with prostate volumes of more than 100 ml, energy delivery of 400 kJ or more was not required in any of the procedures in our study. Therefore, it remains unknown whether the performance of fibers with very high-energy delivery (400–650 kJ) still remains on the same constant level that was seen in fibers that delivered 150–400 kJ.

Heat accumulation at the fiber tip and inadequate heat resistance of the fiber have been reported to be the main reasons for fiber degradation [11, 17]. These issues have been addressed for the 180 W XPS™ laser by improvements in fiber design. The novel MoXy™ laser fiber with integrated water cooling and temperature control sensor at the fiber tip decreases heat accumulation and vulnerability of the fiber tip. However, even these thoughtful improvements in fiber design do not completely prevent fiber degradation and loss of power output. Heat accumulation mainly occurs when vaporization is performed with fiber-tissue contact which cannot always be prevented (e.g., during tissue coagulation, bladder neck incision, or vaporization of the so-called "kissing lobes"). Our non-contact in vitro LV confirmed previous observations, showing that fiber performance was constant when fiber-tissue contact was completely avoided [1, 10, 14, 15, 20].

In the current investigation, 1/4 of the fibers showed a drastic decrease of power output and 6 fibers were replaced due to premature degradation. This number appears to be relatively high particularly considering that the median prostate volume was not exceptionally high in the present study. In three of these fibers, close fiber-tissue contact was identified as the reason for premature degradation. However, two fibers also showed malfunction that was most likely related to insufficient quality of the fibers.

It is important to mention that the surgeon-estimated fiber performance seems to correlate nicely with the measured performance of the laser during the procedure. This is particularly relevant for the fibers with a drastic decrease of power output that are optimally to be replaced to prevent inefficient vaporization. Although the surgeons were not informed about the results of the intraoperative measurements, they were able to identify the fibers with poor performance. The fibers with an estimated poor performance had a markedly lower final output measured (10%) compared to the groups with an estimated good (65%) and moderate performance (55%). Furthermore, five of the six fibers that were replaced during the procedure had a drastic decrease in power output (> 80%) in the actual measurements.

Limitations to our investigation were mentioned previously [14]. The measurement setup used in our investigation was not formally validated. However, it represents a simple physical measurement setup that was constructed in collaboration with the renowned Swiss Federal Institute of Technology (ETH). Furthermore, our study was not powered to identify specific risk factors for fiber degradation and loss of power output. Different vaporization techniques, differences in experience of the surgeons, and different characteristics of the investigated patient cohort (e.g., prostate volume) might influence the performance of the laser fibers [22]. Larger, prospective investigations are needed to identify the best technique for specific situations to allow for an optimal performance of the laser with the best possible outcome.

Conclusions

Degradation of laser fiber associated with a decrease in power output is still an issue during 180 W GreenLight XPS™ LV. Whether modifications of the surgical technique can prevent impairment of fiber performance needs to be further evaluated.

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Authors' contribution TH: protocol/project development, data collection and management, data analysis, manuscript writing and editing. NCG: protocol/project development, data collection and management, data analysis, manuscript writing and editing. MSW: protocol/project development, data collection, manuscript writing and editing. EXK: data collection and management, manuscript writing and editing. CDF: data collection and management, manuscript writing and editing. OG: data collection and management, manuscript writing and editing. BK: data collection and management, manuscript writing and editing. ML: data collection and management, manuscript writing and editing. AHM: technical support, data collection and management, manuscript writing and editing. TS: data collection and management, manuscript writing and editing. CP: protocol/project development, data collection and management, data analysis, manuscript writing and editing.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the local ethics committee (KEK-ZH-Number: 2012-518).

Informed consent Informed consent was obtained from all individual participants included in the study.

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