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Abstract

Despite technical refinements of the 120 W lithium-triborate laser fiber degradation and significantly decreased power output are still detectable during the procedure. Laser fibers are not fully appropriate for the high power delivery of the new system. There is still potential for further improvement in the laser performance.
Lithium Triborate-Laser Vaporisation of the Prostate using the 120W High Performance System (HPS) Greenlight-Laser: High Performance all the Way?

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Runninghead: Performance of the LBO laser during prostate vaporisation

Keywords (MESH): Benign prostatic hyperplasia, Laser fibre, Laser prostatectomy, Prostate, Transurethral resection of prostate/instrumentation

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Abstract

Purpose: The technical modifications of the 120W lithium-triborate (LBO) laser have been implemented to increase the power output and to prevent laser fibre degradation and loss of power output during laser vaporisation (LV) of the prostate. However, visible alterations at the fibre-tip and the subjective impression of a decreasing ablative effectiveness during LBO-LV indicate that the delivery of a constantly high laser power remains a relevant problem. Therefore, the extent to which laser fibre degradation and loss of power output take place during 120W LBO-LV of the prostate was evaluated.

Material and Methods: Forty-six laser fibres were investigated during routine 120W LBO-LV in 35 patients suffering from prostatic bladder outflow obstruction. Laser beam power was measured at baseline and after the application of every 25kJ during LV. The fibre-tips were microscopically examined after the procedure.

Results: Mild to moderate degradation at the emission window associated with a loss of power output occurred in all fibres. A steep decrease to a median power output of 57.3% of the baseline value was detectable after the application of the first 25kJ. The median power output at the end of the defined 275kJ-lifespan of the fibres was 48.8%.

Conclusions: Despite the technical refinements of the 120W LBO-laser, fibre degradation and a significant decrease of power output are still detectable during the procedure. The laser fibres are not fully appropriate for the high power delivery of the new system. Thus, there is still potential for further improvement of the laser’s performance.
**Introduction**

Since its clinical introduction for prostatic de-obstruction in 1998, the 532nm greenlight laser system has experienced numerous modifications in order to optimize its performance.\(^1\)-\(^3\) The early low-powered 60W potassium-titanyl-phosphate (KTP) laser system was soon to be replaced by the more potent 80W system, which found a wide acceptance in urological practice at the beginning of this century.\(^2\), \(^4\)-\(^7\)

Despite excellent clinical short- to mid-term results\(^8\)-\(^12\) several weak points of the procedure have also been identified.\(^13\)-\(^15\) Prolonged irritative voiding symptoms and post-operative urinary retention have been described as typical side effects of KTP-laser vaporisation (LV).\(^9\), \(^15\) Laser fibre degradation leading to a significant loss of power output during the operation has been identified as one possible reason for post-operative voiding problems.\(^13\)

The reduced power output results in inefficient tissue ablation and increased tissue coagulation.\(^16\), \(^17\) The latter is known to cause post-operative irritative voiding symptoms, whereas insufficient tissue ablation might impair the long-term efficacy of the procedure.\(^18\), \(^19\)

The typical problems of the KTP-laser called for further technical refinements. In 2006 the 120W high performance system (HPS) lithium triborate (LBO) laser has been introduced. Higher power and modifications of the laser beam leading to a faster and more efficient non-contact vaporisation have been reported.\(^3\) Surgically, an improved performance was clearly evident. However, macroscopic alterations of the fibre-tip and a decreasing ablative efficiency during the procedure again became apparent. The objective of the present investigation was to evaluate the performance of the HPS system with regard to structural changes of the laser fibre and associated changes in power output during treatment.

**Material and Methods**

LBO-LV was performed using the 120W GreenLight HPS™ laser (AMS®, Minnetonka, MN, USA). Between July 2008 and August 2009, 46 IQ™ Greenlight HPS® bPH fibres (AMS®)
were investigated during routine LBO-LV in 35 patients suffering from prostatic bladder outflow obstruction. Patient characteristics are summarised in table 1. Two experienced surgeons (300-500 previous LV) and two novices performed the operations as described earlier. The local ethics committee approved the study protocol (StV-Nr.16/2007) and all patients provided written informed consent.

Laser beam power measurements were performed at baseline and after the application of every 25kJ throughout the LV procedure. For the measurements, a custom-built fibre holder was used to hold the fibre in a fixed position (figs. 1, 2). After positioning of the fibre, the laser was shortly activated at 120W output power. After its emission from the fibre, the laser beam had to be attenuated to allow a precise measurement with a short release time (figs. 1, 3). Thus, the PM121 optical power meter (Thorlabs, Dachau, D) constantly measured 0.49% of the emitted power (fig. 1).

For the analyses, the baseline value of each individual fibre was defined as 100%. Subsequent values in each measurement series were calculated and expressed as a percentage of this baseline value.

To investigate if the clinical estimation of the fibres’ performance was in line with the results of the measurements, the surgeons stated when a decrease of the vaporisation efficiency became apparent during the operation and estimated the overall decrease of power output in percent after the operation. The surgeons were blinded to the results of the performed measurements. After the procedure the fibre-tip was microscopically examined and the degree of degradation was classified to be mild (i.e. superficial whitening), moderate (i.e. superficial melting) or severe (i.e. deep melting or complete destruction of the fibre-tip).

The impact of the surgeons’ experience on the performance of the fibres during the operation was analysed by comparing the course of power output between two groups of patients operated by experienced or inexperienced surgeons, respectively.
Power measurements during non-contact in-vitro vaporisation were performed to investigate the performance of two fibres up to 275kJ in a setting without any fibre-tissue contact as described earlier.\textsuperscript{13}

Two additional fibres with only a baseline and a terminal measurement before and after a regular 275kJ-LV were investigated to further define the impact of the measurement procedure itself on the course of power output.

Follow-up examinations were done 6 weeks and 6 months post-operatively. At each follow-up visit, subjective (International Prostate Symptom Score and quality of life) and objective outcome parameters (maximum flow rate, residual volume and PSA-value) were recorded. Furthermore, patients were asked to report if bothering irritative voiding symptoms appeared.

Statistical analysis was performed using the Predictive Analytics Software version 18 (SPSS Inc, Chicago, IL, USA). Continuous variables were compared using the Wilcoxon signed-rank test. All p-values <0.05 were considered significant.

**Results**

Intra-operative results are summarised in table 2. A total of 24 procedures (68.6\%) were completed using one fibre only. High prostate volume or early fibre degradation resulted in nine patients (25.7\%) requiring the use of a second fibre and two patients (5.7\%) requiring three fibres, of which only the first two were investigated in each case.

By the end of the procedure, all fibres showed some degree of fibre degradation caused by melting and carbonisation at the emission window. These alterations slightly increased in parallel to the total amount of energy applied (fig. 4). Mild damage of the tip was found in the fibres from regular LV with less than 175kJ applied and from non-contact in-vitro vaporisation (figs. 4, 5). Moderate damage was found in fibres from LV with 175kJ or more applied (fig. 4). Severe damage resulted from extensive, unavoidable contact vaporisation (two fibres) or from exposure of the laser beam to prostate stones (one fibre; fig. 5).
The baseline values of the 46 fibres showed a certain inter-fibre variation (tab. 3). However, the course of power output was similar for all fibres. Typically, a steep decrease of power output within the first 25kJ was followed by a continuous mild decrease until the end of the procedure (fig. 6). After the application of 25kJ the median power output was 57.3% (interquartile range (IR): 50.2-69.6%) of the baseline value. This reduction of power output was statistically significant (tab. 3). The median power output at the end of the 275kJ-lifespan of the fibres was 48.8% (IR: 40.5-52.5%). None of the fibres had a stable course without any decrease of power output.

The surgeons noted a decline of the vaporisation efficiency after the application of median 100kJ (range 75-200kJ). The median estimated decrease of power output at the end of the operation was 60% (range 0-80%).

The course of power output of the two fibres tested in-vitro without fibre-tissue contact was similar to the course of the fibres tested in-vivo but the decrease of power output was less extensive. The median power output was 65% of the initial value after the application of 50kJ and 58.9% after the application of 275kJ.

The decrease of power output of the two controls with only a baseline and an endpoint measurement was no different than that of the 46 regular measurements (data not shown).

The pre-operative prostate volume was not significantly different in the group of patients operated by experienced (group I) and inexperienced surgeons (group II). Although the lasing time was longer in group I, total operation time and applied total energy was significantly shorter (tab. 2). Median power output was slightly but significantly lower in group II after the application of 25 and 50kJ. Thereafter, power output was not significantly different anymore between the two groups (Fig. 7).

The median duration of catheterization was 2 days (range: 1-13d) and the median post-operative hospital stay 4 days (2-25d). Four patients needed re-catheterization due to hematuria (n=2) or urinary tract infection with high post-void residual volume (n=2). One
patient under oral anticoagulation needed transfusion due to persistent bleeding. Another 86-year-old patient died five days post-operatively due to cardio-pulmonal de-compensation.

After 6 weeks all investigated outcome parameters improved significantly and all patients were catheter-free (table 4). Eleven patients (33%) reported irritative voiding symptoms. Two of those were diagnosed with a urinary tract infection. After 6 months all outcome parameters slightly improved further. Only three patients (11%) reported irritative voiding symptoms. One of those was diagnosed with a persisting obstructive adenoma and received a conventional transurethral resection 6 months post-operatively.

Discussion

The clinical observation of a decreasing ablative efficiency associated with structural changes at the laser beam emission window during 120W LBO-LV has been substantiated in the present investigation. Fibre degradation resulted in a significant loss of power output throughout the operation with a total drop in power output of more than 50%.

Laser fibre deterioration and loss of power output have previously been reported for Nd:YAG- and KTP-laser treatment of the prostate. Heat at the tip of the fibre and insufficient heat resistance of the fibre itself are the main reasons for fibre degradation. During KTP-LV heat accumulation at the fibre-tip is a result of adherent tissue debris and extensive fibre-tissue contact, which is difficult to avoid when performing LV with a recommended sweeping movement and an optimal fibre-tissue distance of only 0.5-1mm. A constant decrease of power output throughout the operation with a final loss of power output of 80% was measurable during 80W KTP-LV. Low power leads to a reduced ablative capacity, which in turn results in insufficient tissue ablation and increased tissue coagulation. The latter is a risk factor for irritative voiding symptoms, while insufficient tissue ablation may result in early prostatic re-obstruction and thus may compromise the long-term efficacy of the procedure. Re-treatment rates up to 50% within
years have been reported after KTP-LV.14 Bothersome post-operative voiding symptoms and high re-operation rates are well known problems after prostatic laser treatment and the main reasons preventing a breakthrough of several laser procedures in the past.24 The novel features of the 120W HPS-laser were introduced to overcome the weaknesses of the KTP-laser. Higher power and an optimized laser beam profile, allowing for a more efficient tissue vaporisation and preventing early fibre degradation, have been reported.3 Higher power together with an optimized laser beam collimation results in a higher power density and thus a stronger ablative capacity. The changes in beam characteristics additionally allow for efficient vaporisation at a greater distance from the tissue (1-3mm). This important innovation facilitates non-contact LV and consequently prevents fibre degradation and unwanted tissue coagulation.23 The technical modifications markedly improved the performance of the system. The 120W HPS-laser has been shown to be 50% to 100% more efficient than the 80W KTP-laser in-vitro.25-27 Fibre destruction and loss of power output observed in the present investigation are less vigorous than reported after KTP-LV.13 This illustrates that not only the ablative capacity but also the performance throughout the procedure significantly differs between the two lasers. The relatively constant course of power output on a medium level after the initial decrease allows for a more constant performance towards the end of the fibre’s lifespan compared to the KTP-laser and is the main reason for a recently released laser system upgrade. This upgrade extends the lifespan of a single fibre up to 400kJ in order to treat larger glands with a single fibre. The novel features facilitate non-contact LV and have a positive impact on the longevity of the fibre and the course of power output during the procedure. However, a significant problem of the greenlight laser procedure has not been solved by these innovations. Laser fibre degradation and loss of power output are still an issue during HPS-LV. The decrease of power output becomes clinically noticeable evidenced by the surgeons’ rating of the fibre
performance.

The high power of the HPS system together with an inappropriate laser fibre seem to be the most important factor for the decrease of power output during HPS-LV. High power challenges the fibre material to a higher extent\textsuperscript{3} and might effect early alterations of the virgin fibres which, in turn, may cause the early steep decrease of power output observed in the present investigation.

Fibre-tissue contact can more easily be prevented during LBO-LV than during KTP-LV and thus is only a minor reason for fibre degradation and loss of power output. The significant decrease of power output during non-contact \textit{in-vitro} vaporisation also indicates that changes in power output occur largely independently from fibre-tissue contact. If fibre-tissue contact were an important reason for the decrease of power output, it would be more pronounced if inexperienced surgeons do a LV procedure as they more likely vaporize with tissue contact. However, in the present investigation, no major differences in the overall course of power output were detectable between the two groups of patients operated by experienced and inexperienced surgeons.

If fibre-tissue contact is unavoidable under certain circumstances (e.g. a large median lobe or tight prostatic urethra), the distinct vulnerability of the HPS fibre becomes apparent. Three laser fibres were destroyed early during inevitable contact-vaporisation or exposure of the beam to prostate stones in the present investigation. The variances of the baseline power output values, the regularly seen satellite beams laterally to the main beam and an often observed imprecise alignment of the emission window and the positioning pin of the guiding knob are other factors pointing out that an upgrading in laser fibre quality is indicated.

From the clinical point of view, the decrease of power output seems to be relevant as well. In the present investigation 33\% of the patients reported irritative voiding symptoms and one patient needed re-operation due to persisting adenoma during a six months follow-up period. The typical side effects and need for re-operations have also been reported by others after
Most recently, the new 180W XPS laser system has been introduced. The HPS fibres can be used for the new system but only with 120W and not with 180W output power. Therefore, a novel fibre (MoXy™) with integrated water-cooling and a temperature-control sensor at the fibre-tip has been released. However, this fibre cannot be used for the 120W HPS-laser. It is desirable that the MoXy™ fibre meets the demands of XPS laser system and finally allows for a greenlight laser performance with a constantly high efficiency.

Some limitations of the present investigation deserve mention. Due to inhomogeneities of the laser fibres (e.g. position of the emission window, alignment of the positioning pin) the standardised set-up with its fixed fibre position might have generated the inter-fibre variances of the baseline power outputs to some extent. However, the exact measurement of the course of power output of the single fibres was guaranteed by this fixation. Furthermore, the extent of the structural and functional changes might only be valid for the operative technique performed in this investigation.

Conclusions:

The technical refinements of the 120W HPS-laser have been implemented in order to improve the tissue ablative properties and the longevity of the laser fibre. However, fibre degradation and a significant decrease of power output are still detectable during HPS-LV. This is mainly due to the laser fibres, which are not fully appropriate for the high power delivery of the new system. Thus, there is still potential for further improvement of the laser’s performance.
Acknowledgements:

The authors thank Eliane Irschara for the design and construction of the fibre holder, Alexandra Veloudios for the organisation of the patient care during the investigation and Damina Balmer for her editorial assistance. This work forms part of the doctoral thesis of Daniel Strebel.

References:


29. M. Spaliviero, M. Araki and D.J. Culkin et al., Incidence, management, and prevention of perioperative complications of GreenLight HPS laser photoselective
vaporization prostatectomy: experience in the first 70 patients, J Endourol 23 (2009), p. 495.

**Figure legends:**

**Figure 1:** Fibre holder and measurement setup: The middle and distal brackets of the holder (black arrowhead) fix the fibre (black arrow) using a snap fit. The laser beam, emitted from
the fibre-tip (white arrow) is refocused by a lens (f=25.4mm; small white arrowhead) and attenuated and redirected onto the detector (asterisk) by two 16 BPB 153 Fresnel beam samplers (Melles Griot, Bensheim, D; large white arrowhead) each of which reflects approximately 7% of the light, whereas 93% are transmitted.

**Figure 2:** The laser fibre is placed in the large notch (black arrow) of the proximal bracket. The positioning pin (black arrowhead) of the guiding knob (asterisk) is stuck into the small notch (white arrow) to guarantee a steady longitudinal and rotational position of the laser beam for each measurement series.

**Figure 3:** Schematic drawing of the measurement setup with the course of the green laser beam (BS = beam sampler).

**Figure 4:** Fibre deterioration in the region of laser emission caused by melting and carbonisation. The alterations slightly increased together with the total energy applied. A virgin fibre can be seen on the left side, a fibre after 275kJ 80W KTP-LV on the right side. Scale bar: 2 mm.

**Figure 5:** Impact of fibre-tissue contact: The laser fibre shows only slight degradation at the emission window following strict non-contact (NC) *in-vitro* vaporisation. Massive fibre deterioration however can be seen after vaporisation with unavoidable tissue contact (TC) due to a large median prostate lobe. Complete destruction of the fibre-tip can be seen after exposure of the laser beam to prostate stones (PS).
**Figure 6:** Median and interquartile range of all 46 measurement series. Following an early steep decrease, power output remained relatively constant on a medium level for the rest of the 275kJ fibre's lifespan.

**Figure 7:** Courses of median power output of two groups of patients: group I operated by experienced and group II by inexperienced surgeons.
Figure 6
### Table 1: Pre-operative parameters of 35 patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>35</td>
</tr>
<tr>
<td>Age (y)</td>
<td>70 (49-88)</td>
</tr>
<tr>
<td>Prostate volume (ml)</td>
<td>55.2 (24.4-160.2)</td>
</tr>
<tr>
<td>BPH</td>
<td>32 (91.4%)</td>
</tr>
<tr>
<td>Prostate cancer</td>
<td>3 (8.6%)</td>
</tr>
<tr>
<td>PSA (ng/ml)</td>
<td>3.47 (0.6-34.6)</td>
</tr>
<tr>
<td>IPSS / QoL</td>
<td>17.5 (9-32) / 3 (1-6)</td>
</tr>
<tr>
<td>Qmax (ml/sec)</td>
<td>9.0 (2.3-21.9)</td>
</tr>
<tr>
<td>Residual volume (ml)</td>
<td>69 (0-360)</td>
</tr>
<tr>
<td>Indwelling catheter</td>
<td>9 (26%)</td>
</tr>
<tr>
<td>Anticoagulation (CD/PAI)</td>
<td>21 (60%) (3/18)</td>
</tr>
</tbody>
</table>

Data are presented as median (range) or number (percent); BPH = benign prostatic hyperplasia, PSA = prostate-specific antigen, IPSS = International Prostate Symptom Score, QoL = quality of life, Qmax = maximum flow rate, CD = coumarin derivates, PAI = platelet aggregation inhibitors.
Table 2: Intra-operative parameters of the 35 patients in total and subdivided into two groups of patients operated by experienced or non-experienced surgeons.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Group I: experienced surgeons</th>
<th>Group II: inexperienced surgeons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>35</td>
<td>24 (68.5%)</td>
<td>11 (31.5%)</td>
</tr>
<tr>
<td>Number of fibres</td>
<td>46</td>
<td>31 (67.4%)</td>
<td>15 (31.6%)</td>
</tr>
<tr>
<td>Operation time (min)*</td>
<td>90 (35-180)</td>
<td>80 (35-150)</td>
<td>100 (70-180)</td>
</tr>
<tr>
<td>Lasing time (min)</td>
<td>39 (22-90)</td>
<td>42 (29-90)</td>
<td>38.5 (22-68)</td>
</tr>
<tr>
<td>Applied energy per fibre (kJ)</td>
<td>215 (50-275)</td>
<td>217.5 (64-275)</td>
<td>215 (50-275)</td>
</tr>
<tr>
<td>Applied energy per patient (kJ)*</td>
<td>270 (124-636)</td>
<td>238 (129-636)</td>
<td>273 (124-428)</td>
</tr>
</tbody>
</table>

Data are presented as median (range) or number (percent). * Indicates a significant difference between the two groups.
**Table 3:** Total number of fibres, median power output, and range after the application of n kJ

<table>
<thead>
<tr>
<th>Applied energy (kJ)</th>
<th>0</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
<th>200</th>
<th>225</th>
<th>250</th>
<th>275</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fibres</td>
<td>46</td>
<td>46</td>
<td>45</td>
<td>45</td>
<td>44</td>
<td>40</td>
<td>35</td>
<td>32</td>
<td>29</td>
<td>22</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Median power output (mW) (^1)</td>
<td>526</td>
<td>284</td>
<td>296</td>
<td>276</td>
<td>282</td>
<td>264</td>
<td>256</td>
<td>265</td>
<td>230</td>
<td>268</td>
<td>238</td>
<td>254</td>
</tr>
<tr>
<td>Range of power output (mW) (^1)</td>
<td>328-674</td>
<td>141-511</td>
<td>128-419</td>
<td>103-446</td>
<td>100-396</td>
<td>63-399</td>
<td>93-408</td>
<td>82-490</td>
<td>78-437</td>
<td>79-429</td>
<td>80-363</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
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</table>

* As measured by the power detector (0.49% of the fibre output power)

* Indicates a significant decrease of the median power output compared to the baseline value (p < 0.05).
Table 4: Postoperative outcome

<table>
<thead>
<tr>
<th></th>
<th>6 weeks</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of patients</strong></td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td><strong>IPSS / QoL</strong></td>
<td>6 (1-24) / 1 (0-6)</td>
<td>4.5 (0-22) / 1 (0-5)</td>
</tr>
<tr>
<td><strong>Qmax (ml/sek)</strong></td>
<td>20.3 (6.8-40.4)</td>
<td>20.6 (9.4-32.1)</td>
</tr>
<tr>
<td><strong>Residual volume (ml)</strong></td>
<td>21.5 (0-250)</td>
<td>13 (0-171)</td>
</tr>
<tr>
<td><strong>PSA (ng/ml)</strong></td>
<td>2.53 (0.3-28.1)</td>
<td>1.95 (0.27-9.07)</td>
</tr>
<tr>
<td><strong>Indwelling catheter</strong></td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td><strong>Irritative voiding symptoms + UTI</strong></td>
<td>11 (33%)</td>
<td>3 (11%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Data are presented as median (range) or number (percent); IPSS = International Prostate Symptom Score, QoL = quality of life, max = maximum flow rate PSA = prostate-specific antigen, UTI = urinary tract infection