Thermal lasers in urology

Malte Rieken*, Alexander Bachmann

Department of Urology, University Hospital Basel, Spitalstrasse 21, 4031 Basel, Switzerland

Received 14 September 2009; accepted 20 October 2009

Abstract

The thermal effect is the most common effect of tissue–laser interaction in urology. With the widespread use of endoscopic instruments laser applications in urology have dramatically increased. Various urological conditions can nowadays be successfully treated with lasers. In the treatment of benign prostate hyperplasia (BPH), holmium laser enucleation of the prostate (HoLEP) and photoselective vaporization of the prostate (PVP) have proven as reliable, safe and effective treatment alternatives. Urethral strictures, bladder neck sclerosis and ureteropelvic junction (UPJ) obstruction have also been treated successfully with lasers; however their role is limited to selected cases and conditions. For the treatment of malignant diseases, lasers can be applied in early stage upper urinary tract transitional cell carcinoma (UUTTCC) and penile carcinoma. This review summarizes the potential and limitations of thermal lasers in urology.

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Keywords: Laser surgery; Thermal lasers; Benign prostate hyperplasia; Upper urinary tract transitional cell carcinoma; Penile carcinoma

Introduction

Lasers in urology have been subject to intense research since the 1980s. The most commonly used effect of tissue–laser interaction is the thermal effect. The light energy emitted by the laser is absorbed by the tissue and transformed into heat. Depending on the temperature reached in the tissue, a denaturation of proteins, shrinkage of arteries and veins, cellular dehydration, carbonization, or vaporization occurs. The tissue can be incised, coagulated or vaporized (Table 1). Laser applications have dramatically increased with the rapid development and continuous improvement of endoscopic instruments. In the treatment of benign prostate hyperplasia (BPH), the application of lasers is an established treatment alternative, while other applications of lasers are still controversial and under investigation. This review gives an updated overview of the application of thermal lasers in the treatment of various urological conditions.

Benign prostate hyperplasia

Lower urinary tract symptoms (LUTS), due to benign prostate enlargement by BPH, are a highly prevalent disease. At the age of 60 years, nearly 60% of men have some degree of clinical BPH [1]. The most common indication for surgery are LUTS refractory to medical treatment, refractory or recurrent urinary tract infections, recurrent hematuria, renal insufficiency due to obstruction or bladder stones [2]. Transurethral
resection of the prostate (TURP) is regarded as the gold standard in men with a prostate size that is smaller than 80 ml, whereas open prostatectomy (OP) is performed for prostates above 80–100 ml [2]. Despite the widespread use of TURP and OP, both techniques can be associated with severe complications and treatment-associated morbidity [3–6]. In recent years, various laser techniques have been developed to overcome complications encountered with TURP or OP (Table 2).

### Holmium laser enucleation of the prostate (HoLEP)

The Holmium:yttrium–aluminium–garnet (Ho:YAG) laser is a solid state pulsed laser with a wavelength of 2100–2150 nm. Since the light energy is rapidly absorbed by water and cell fluid, a high energy density results in a penetration depth of 0.4 mm in prostatic tissue. With the laser, tissue can be precisely incised, dissected and enucleated. The enucleated tissue is morcellated in the bladder and removed. With the introduction of the mechanical tissue morcellator, a rapid development of the enucleation technique was initiated, which has proven to be superior over the now largely abandoned holmium laser ablation of the prostate (HoLAP) and holmium laser resection of the prostate (HoLRP) [7,8].

Numerous trials have shown the low intra- and postoperative complication rate of HoLEP alone or in comparison to TURP or OP at comparable functional outcome [9–12]. In recent years, a considerable number of studies have become available regarding the intermediate and long-term outcome of HoLEP, some of them in comparison to TURP or OP. Gilling et al. [13] reported long-term data with a mean follow-up of 6.1 years showing that the HoLEP results are long-lasting and most patients remain satisfied. Two meta-analyses assessed available randomized controlled trials comparing HoLEP and TURP [14,15]. Both analyses reported a significantly shorter catheterization time and hospital stay, a smaller blood loss and fewer blood transfusions but a longer operation time with HoLEP. Improvement of symptoms was comparable; Lourenco et al. [15] reported a peak flow rate at 12 months, which was significantly in favor of HoLEP. In prostates larger than 100 ml, HoLEP proved to be as effective as OP regarding improvement in micturition with equally low reoperation rates at 5-year follow-up [9]. Despite the high intra and postoperative safety, together with the excellent functional outcome, the steep learning curve of the technique will probably inhibit HoLEP’s widespread use and will restrict its use to a few high expert centers.

### Photoselective vaporization of the prostate (PVP)

In the early 1990s visual laser ablation of the prostate (VLAP) was introduced with the 1064 nm Neodymium:yttrium–aluminium–garnet (Nd:YAG) laser [16]. The low absorption coefficient resulted in deep coagulative necrosis of the tissue [7]. Since the improvement of symptoms and voiding parameters was inferior to TURP and the rate of reoperations was considerably higher, VLAP has now been abandoned [17,18]. By passing the Nd:YAG-produced beam through a KTP or LBO crystal, a green visible light beam (532 nm) is generated which has a completely different laser beam–tissue interaction. The wavelength is not absorbed by water but strongly absorbed by hemoglobin, resulting in enhanced hemostatic properties. The absorption depth in a vascularized tissue such as the prostate is only 1–3 mm, the high energy density leads to a rapid vaporization of the tissue, which is known as photoselective vaporization of the prostate (PVP) [19,20].

### Table 2. Lasers in the treatment of BPH.

<table>
<thead>
<tr>
<th>Laser type</th>
<th>Wavelength (nm)</th>
<th>Method</th>
</tr>
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<td>Ho:YAG</td>
<td>2100–2150</td>
<td>Holmium laser enucleation of the prostate (HoLEP)</td>
</tr>
<tr>
<td>KTP, LBO (GreenLight)</td>
<td>532</td>
<td>Photoselective vaporization of the prostate (PVP)</td>
</tr>
<tr>
<td>Diode laser</td>
<td>940, 980, 1470</td>
<td>Diode laser vaporization of the prostate</td>
</tr>
<tr>
<td>Tm:YAG</td>
<td>2000</td>
<td>Thulium laser enucleation of the prostate</td>
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### Table 1. Application of thermal lasers in urology.

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<th>Technique</th>
<th>Disease</th>
<th>Laser type</th>
</tr>
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<tr>
<td>Resection, ablation</td>
<td>Benign prostatic hyperplasia (BPH)</td>
<td>Ho:YAG, KTP, LBO (GreenLight)</td>
</tr>
<tr>
<td></td>
<td>Upper urinary tract transitional cell carcinoma (UUTTCC)</td>
<td>Nd:YAG, Ho:YAG</td>
</tr>
<tr>
<td></td>
<td>Penile carcinoma (early stage)</td>
<td>Ho:YAG, CO2, Nd:YAG</td>
</tr>
<tr>
<td>Soft tissue incisions</td>
<td>Bladder neck strictures</td>
<td>Ho:YAG</td>
</tr>
<tr>
<td></td>
<td>UPJ obstruction</td>
<td>Ho:YAG</td>
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of voiding symptoms and micturition parameters [21–25]. The intraoperative complication rate reported from several studies was low and favorable compared to TURP because no intraoperative blood transfusions were needed and only one study reported a very low postoperative transfusion rate. However, the long-term rate of reoperations and complications such as bladder neck strictures and urethral strictures was comparable to results reported from TURP [24]. One major drawback is the lack of long-term randomized trials comparing TURP with PVP or OP. Only two non-randomized prospective studies and two short-term prospective randomized trials exist which compare PVP and TURP, whereas one study compares PVP with OP [26–30]. PVP shows a comparable functional outcome in the majority of the studies; however long-term results need to be awaited. PVP has been proven to be safe and equally effective in patients undergoing oral anticoagulation treatment, patients with prostates larger than 80 ml or in patients with refractory urinary retention [31–37].

**Diode laser vaporization of the prostate**

Diode lasers for the treatment of BPH are currently available at the wavelengths 940, 980 and 1470 nm. In a preclinical *ex-vivo* model of the blood-perfused porcine kidney, the 980 nm diode laser has shown a higher tissue ablation capacity, similar hemostasis and a smaller coagulation zone than the KTP laser [38]. Data concerning the coagulation zone could not be confirmed by other authors, showing a five to nine times deeper necrosis zone than the KTP laser in *ex-vivo* investigations on porcine kidneys and human cadaver prostate tissue [39,40]. *Ex-vivo* studies with a 1470 nm, 50-W and a 940 nm diode laser, showed a significantly lower capacity for tissue ablation and a significantly larger coagulation zone compared to the 80-W KTP laser [41,42].

Currently only a few studies have investigated the clinical applications. With a maximum follow-up of 1 year further studies are essential in order to evaluate the technique. While all the studies show a high intraoperative safety and hemostatic properties superior to PVP, reports on the long-term durability and safety are inconsistent with a reoperation rate of up to 32.1% [56,57]. Since there is a lack of prospective randomized trials comparing both techniques and the system exhibits favorable hemostatic properties and safety in comparison to TURP [52]. Currently only data with a maximum follow-up of 1 year are available. The reoperation rate is between 2.8 and 3.1% and no significant difference could be detected in comparison to TURP. Despite the encouraging results, further studies are essential to confirm these data.

**Ureteropelvic junction obstruction, bladder neck sclerosis, urethral strictures**

Ureteropelvic junction (UPJ) obstruction is a narrowing in the junction of the renal pelvis and the ureter leading to anatomical or functional obstruction, whereas bladder neck sclerosis (BNS) and urethral strictures are a narrowing of the bladder neck or the urethra, occurring after surgery, post-inflammation or injury. Despite their different etiology, all the above named conditions can be treated with tissue incision by Ho:YAG laser.

Retrograde laser endopyelotomy is a safe and effective, minimally invasive alternative to pyeloplasty in the treatment of UPJ obstruction. A study of 23 patients reported a success rate of 83% of Ho:YAG endopyelotomy combined with intraluminal ultrasound [53], whereas a symptomatic success rate of 65.4% was reported from another series [54]. In a randomized trial comparing Accucise™ balloon endopyelotomy and Ho:YAG endopyelotomy, comparable results and a lower complication rate in the laser group were observed; however the differences were not statistically significant [55]. Since laparoscopic and retroperitoneoscopic pyeloplasty have largely replaced open surgery and shown favorable success rates with low morbidity, the need for endoscopic pyeloplasty will remain limited.

Laser incision of urethral strictures with the Ho:YAG laser can be performed with low intra- and postoperative morbidity. The short-term success rate is comparable to the outcome of cold knife internal urethrotomy with a reoperation rate of around one third of the patients [56,57]. Since there is a lack of prospective randomized trials comparing both
endoscopic methods and recently, indications for open surgery urethroplasty have been expanded, the role of laser urethrotomy will be limited to selected cases with an increased risk of intraoperative bleeding.

Only a few data are available which investigate the role of the Ho:YAG laser in the management of bladder neck strictures. The procedure can be performed safely and results in comparable outcome to conventional resection of the bladder neck [58].

Upper urinary tract transitional cell carcinoma

Upper urinary tract transitional cell carcinoma (UUTTCC) is a rare condition occurring in around 5% of all TCC. Around 60% of the tumors are invasive at the time of diagnosis [59]. Nephroureterectomy with bladder-cuff removal is the standard treatment for UUTTCC. However, alternative techniques are necessary for a significant proportion of patients due to renal insufficiency, solitary kidney or significant comorbidities. With the further development of endoscopes, UUTTCCs are easier to access for treatment. The Nd:YAG and the Ho:YAG laser are the most commonly used lasers in the treatment of UUTTCC, moreover thulium lasers and diode lasers have been investigated in the treatment of UUTTCC [60]. With the application of lasers, sufficient hemostasis and ablation or resection of tissue can be achieved which results in a low overall treatment-associated morbidity. The recurrence rates for low grade (G1, G2) and low stage tumors (Ta, T1, Tis) are around 35%, while recurrence increases to 47% in high grade (G3) and high stage (≥T2) tumors [59]. Thus, cases undergoing endoscopic management of UUTTCC should be carefully selected.

Penile carcinoma

Penile carcinoma is a rare tumor with an incidence rate of 1 in 100,000 in western countries. Traditional surgical treatment was an amputation of the glans penis 2 cm proximal of the tumor. Since surgery results in severe functional impairment, disfigurement and impaired quality of life, penis preserving strategies have been developed for early stage penile carcinoma. The European Association of Urology recommends CO2 or Nd:YAG laser surgery as a treatment option for Tis and Ta lesions and T1G1 lesions of the glans [61]. In a study of 224 patients with in situ and T1 penile carcinoma, complete excision could be obtained in 98.7% at the lateral margin and 96.9% at the depth margin, with a low intra- and postoperative complication rate. The 10-year recurrence rate was 17.5%, the 10-year amputation rate 5.5% [62].

Conclusions

The last few years has seen a tremendous increase in the application of thermal lasers in urology. Various benign and malignant conditions can be treated effectively. The primary indication for thermal lasers is the treatment of symptomatic prostate enlargement due to BPH. HoLEP, and to a lesser extent, PVP, have proven to be equally effective as a standard treatment with a favorable intra- and postoperative morbidity. Other laser types, such as thulium and diode lasers, have shown encouraging results which need to be confirmed in the future to define their role. In the treatment of UPJ obstruction lasers have been investigated successfully and have shown a low intraoperative morbidity. However, their role remains limited since laparoscopy and retroperitoneoscopy have replaced open surgery and produce superior results with comparable treatment-associated morbidity. The role of lasers in the treatment of urethral strictures or bladder neck sclerosis is limited to cases with increased intraoperative risk of bleeding. Endoscopic approaches for the therapy of UUTTCC remain reserved for selected early stage cases or palliative situations. In the treatment of early stage penile cancer, lasers have contributed to an improvement of functional outcome while maintaining oncological safety.

Zusammenfassung

Thermische Laser in der Urologie


Schlüsselwörter: Laserchirurgie; Thermische Laser; Benigne Prostatahyperplasie; Urothelkarzinom des oberen Harntrakts; Peniskarzinom
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