EUROPEAN UROLOGY 61 (2012) 317–325

available at www.sciencedirect.com
journal homepage: www.europeanurology.com

European Association of Urology

Review – Benign Prostatic Obstruction

Laser Treatment of Benign Prostatic Obstruction: Basics and Physical Differences

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Article info

Article history:
Accepted October 13, 2011
Published online ahead of print on October 21, 2011

Keywords:
Laser
BPH
BPO
Laser radiation
Fibre technology
Laser–tissue interaction
GreenLight laser
Diode laser
Thulium laser
Holmium laser

Abstract

Context: Laser treatment of benign prostatic obstruction (BPO) has become more prevalent in recent years. Although multiple surgical approaches exist, there is confusion about laser–tissue interaction, especially in terms of physical aspects and with respect to the optimal treatment modality.
Objective: To compare available laser systems with respect to physical fundamentals and to discuss the similarities and differences among introduced laser devices.
Evidence acquisition: The paper is based on the second expert meeting on the laser treatment of BPO organised by the European Association of Urology Section of Uro-Technology. A systematic literature search was also carried out to cover the topic of laser treatment of BPO extensively.
Evidence synthesis: The principles of generation of laser radiation, laser fibre construction, the types of energy emission, and laser–tissue interaction are discussed in detail for the laser systems used in the treatment of BPO. The most relevant laser systems are compared and their physical properties discussed in depth.
Conclusions: Laser treatment of BPO is gaining widespread acceptance. Detailed knowledge of the physical principles allows the surgeon to discriminate between available laser systems and their possible pitfalls to guarantee high safety levels for the patient.

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1. Introduction

Transurethral resection of the prostate (TURP) and open prostatectomy are considered the gold standard in the treatment of benign prostatic obstruction (BPO) [1,2]. However, considerable morbidity is associated with both procedures. TURP is associated with low morbidity in smaller prostates, but problems increase with rising volume [1].

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Similarly, open surgery for high-volume glands is coupled with associated morbidity [2,3]. Several laser-based minimally invasive treatment options have been introduced to achieve symptom improvement with reduced morbidity. Although multiple lasers are in use, confusion exists about laser–tissue interaction. Several physical aspects, such as the best possible wavelength and the way of applying laser energy, remain to be clarified.

This structured review is based on the outcome of a European Association of Urology Section of Uro-Technology (ESUT) expert meeting involving physicists, technicians, and urologists focussing on the basic science of laser radiation generation, transmission, and laser–tissue effects. A systematic comparison of the physical backgrounds of the various devices was performed.

2. Evidence acquisition

This paper is based on the second expert meeting on laser treatment of BPO organised by the ESUT. In addition, we performed a systematic literature search using the Medline, Embase, and PubMed databases. Inclusion criteria were meta-analyses, randomised controlled studies, reviews, and controlled cohort and experimental studies providing information on basic laser science and application for treatment of BPO. In addition, we included the expert opinions of participating urologists, physicists, and representatives of European and American laser companies.

3. Evidence synthesis

3.1. Generation of laser radiation

Laser is an acronym for "light amplification by stimulated emission of radiation." The envelope "light radiation" shows that escaping energy is simply light of a defined wavelength and direction. This light is created by a quantum mechanical principle of "stimulated emission" of radiation of an excited laser medium (active media: gas, crystal, glass, dye). Excitation of the laser medium can be achieved by various principles (eg, excitation by photons from a flash lamp). Some of the excitation photons are absorbed by the active medium, leading to an increased energy level (excited states). According to the theory of spontaneous emission, these excited states return to the ground state, statistically releasing a photon at a characteristic wavelength. If these spontaneously emitted photons hit another excited laser medium ion, it stimulates the excited ion to return to the ground state by emitting a further photon with the same wavelength and direction of propagation. This is called *stimulated emission of radiation* (Fig. 1) [4]. The emitted wavelength is defined by the active components of the lasing medium.

For purposive excitation of the laser medium, it is embedded into an optical resonator, a set of mirrors within the optical axis of the laser medium redirecting emerging photons into the laser medium for further amplification of the laser radiation (Fig. 2). One of the resonator mirrors shows a reflectivity at the laser wavelength of nearly 100% (high reflector), and the other one is partially transparent to allow laser radiation to exit from the resonator (output coupler). Laser radiation is emitted from the resonator in a continuous wave or pulsed manner depending on the construction of the laser device (eg, excitation source, characteristics of the laser medium) or the presence of additional optical elements, such as a Q-switch.

Q-switching is a technique to generate short high-peak power laser pulses by modulating the cavity Q factor (cavity loss) of the laser resonator. It comprises an optoelectronic shutter that is embedded within the laser resonator. This shutter is periodically opened and closed. When the shutter is closed (low-cavity Q factor), stimulation of emission is suppressed, but the population inversion reaches a large value due to the ongoing excitation process. When the shutter opens (high-cavity Q factor), spontaneously emitted photons start oscillating within the resonator leading to an avalanche of stimulated emission. The larger the population inversion, the higher the Q-switch pulse peak power. The Q-switch pulse terminates with depletion of the population inversion.

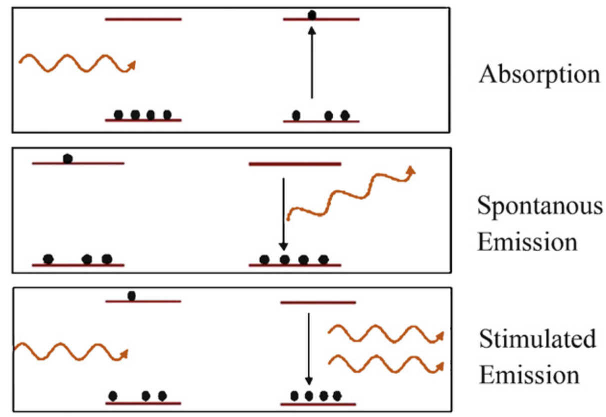

Fig. 1 – Spontaneous and stimulated emission of radiation. Courtesy of Roland Sroka, Munich, Germany.

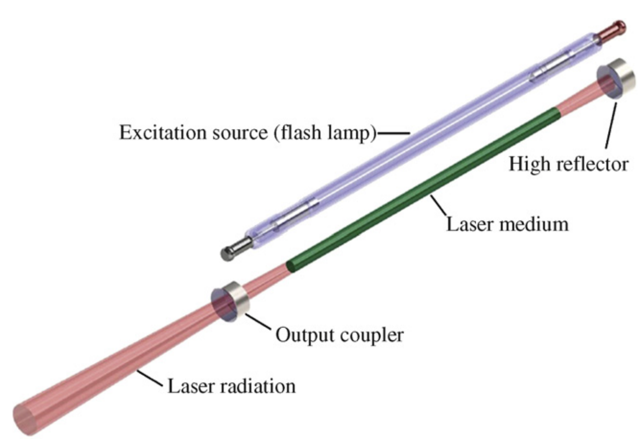

Fig. 2 – Optical resonator with excitation source (flash lamp). Green bar: laser medium; right end: high reflector; left end: output coupler; red beam: laser radiation. Courtesy of LISA Laser, Katlenburg, Germany.

Table 1 – Laser energy sources

Physical properties of laser systems used for benign prostatic obstruction treatment				
Common name	Active medium	Excitation source	Wavelength, nm	Mode of operation
Solid state/crystal				
Holmium laser	Cr^{3+}, Tm^{3+}, Ho^{3+}:YAG	Flash lamp	2123	Pulsed mode
KTP/LBO laser	Nd^{3+}:YAG	Arc lamp Laser diode	532	Quasi-continuous mode, continuous mode
Thulium laser	Tm^{3+}:YAG	Laser diode	2013	Continuous mode
Diode laser systems				
Diode laser	Semiconductor structure GaAlAs (750–870 nm) InGaAs (900–1000 nm) InGaAsP (1300–1550 nm)	Electrical current	940, 980, 1318, 1470	Continuous mode

CR = chromium; Tm = thulium; Ho = holmium; Nd = neodymium; YAG = yttrium-aluminium-garnet; KTP = potassium-titanyl-phosphate; LBO = lithium triborate; GaAlAs = gallium-aluminium-arsenide; InGaAs = indium-gallium-arsenide; InGaAsP = indium-gallium-arsenide-phosphide.

Multiple laser media are used to generate laser radiation. In the treatment of BPO, four laser systems are currently in use, including crystal (holmium:yttrium-aluminium-garnet [Ho:YAG], thulium:YAG [Tm:YAG], SHG-ND:YAG [second harmonic generation-neodymium:YAG], GreenLight [KTP/LBO]) and diode laser systems. They differ in the type of active medium and in the excitation source, leading to various wavelength and emission modes (Table 1).

Second harmonic generation is a second-order nonlinear process used to convert a given laser to half of its fundamental wavelength (second harmonic). It comprises a nonlinear crystal that needs to be carefully matched with the fundamental laser wavelength. Sufficient power density of the fundamental laser and exact alignment of the nonlinear crystal with the direction of propagation is required to generate second harmonic photons, which are double in frequency and/or half in wavelength.

In diode lasers, a semiconductor laser diode is used to generate laser radiation. The semiconductor material defines the wavelength (Table 1). Electrical current flow is used to stimulate the semiconductor, which emits laser radiation after exceeding the threshold. Diode laser systems achieve a high electrical to optical energy conversion efficiency.

In contrast to diode lasers, other cited laser systems utilise a crystal as the laser medium. In these laser systems the active laser ion is doped into the YAG crystal that serves as a carrier for rare earth material defining laser characteristics. The widespread use of the YAG crystal is rooted in its physical properties. With respect to its intended use as an active laser material, this crystal offers three crystallographic sites, $\{C_3\}(A_2)[Al_3]O_{12}$, that are suitable for doping with optically active transition metal and rare earth metal ions. It is optically isotropic and has a broad transparent spectral range. The YAG crystal also offers excellent mechanical and thermal properties. It is easy to grow following the Czochralski technique, which involves growing single crystals from their melt. At the beginning of the growth process, the molten material is kept in a heated crucible. A seed crystal is lowered from above until it reaches the melt surface. The crystal boule is grown by pulling the seed crystal slowly upwards under continuous rotation. The boule diameter at the growth interface is determined by the diameter of melt isotherm. The YAG crystal is also machinable and insoluble in water.

For these reasons the YAG crystal is the material of choice for a variety of solid-state laser materials. By replacing a percentage of the yttrium^{3+} ions at the crystallographic C-position (doping) for three valent rare earth ions like neodymium^{3+}, holmium^{3+}, thulium^{3+}, or erbium^{3+}, optically active solid-state laser materials may be created.

Under excitation these crystals may have the ability to amplify their own fluorescence light by stimulated emission of radiation.

3.2. *Fibres*

Optical fibres deliver laser radiation to the target safely and efficiently, although several issues have to be resolved. Laser radiation has to be coupled from the generator to the fibre and transported within the fibre to the desired point of application.

3.2.1. Fibre construction

A laser fibre includes a circular fibre core and two or more levels of fibre cladding clasped around this core. Laser radiation is delivered through the circular fibre core, whereas the adjacent layer provides entrapment of laser radiation within the core and the remaining layers conserve fibre integrity [5,6]. The optical core is made from silica. Standard silica material is used effectively for visible light, but the transmission of 2-μm radiation by flexible silica laser fibres, as in holmium and thulium lasers, requires purified low hydroxide (OH) silica, to eliminate power loss during the delivery due to energy absorption in the OH^- ion [7].

To launch laser radiation into an optical fibre, a focussing lens with a receptacle for the fibre connector is necessary. Connecting the fibre to the laser generator is critical for energy transmission [8]. A slight deviation of the focal point of the fibre coupler lens leads to laser radiation absorption by ferrule material, which guides the laser fibre to the coupler lens. Thus it will result in heating of the connector

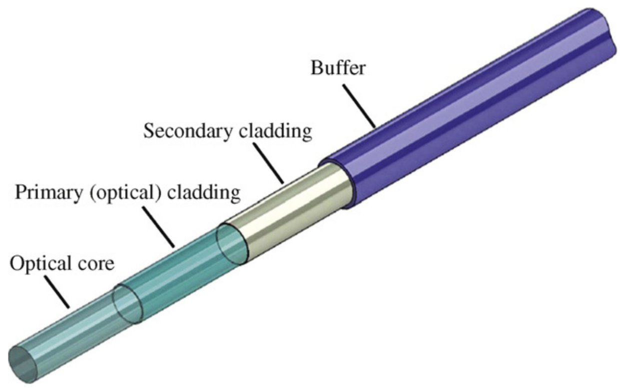

Fig. 3 – Design of a front-firing fibre starting from the inner core: optical core (light blue), primary (optical) cladding (cyan), secondary cladding (silver), and buffer (indigo). Courtesy of LISA Laser, Katlenburg, Germany.

(metal or plastic). At sufficiently elevated power levels, the focused laser beam will melt and vaporise ferrule material resulting in the loss of energy transmission.

To suppress leakage of laser radiation, the core is surrounded by an optical cladding made from a transparent material of a lower refraction index. Fluorine-doped silica cladding is considered the primary choice for high-quality fibre applications. Less flexible fluoroacrylate cladding (TECS) is used for fibres to transmit shorter wavelength and low-power applications [8] (Fig. 3).

3.2.2. Fibre types

Independently of the fibre type, the laser beam is delivered through the optical core of the fibre. In side-firing fibres, the reflection of the laser beam is achieved by an oblique surface at the fibre tip where the radiation is reflected sideways either by total reflection of the beam on a core–air interface or an additional reflective coating. This deflects the laser beam towards the tissue in an oblique angle of about 70°, which is provided by the physics of total reflection at an internal glass–air surface and the angle of polishing (Fig. 4).

By sweeping the beam and changing the distance between fibre tip and tissue surface, coagulation as well as vaporisation can be achieved. Pitfalls of side-firing fibres

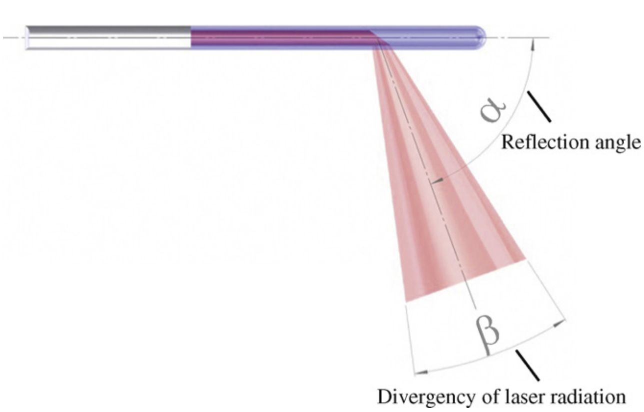

Fig. 4 – Design of a side-firing fibre. α = reflection angle, β = divergence of laser radiation. Courtesy of LISA Laser, Katlenburg, Germany.

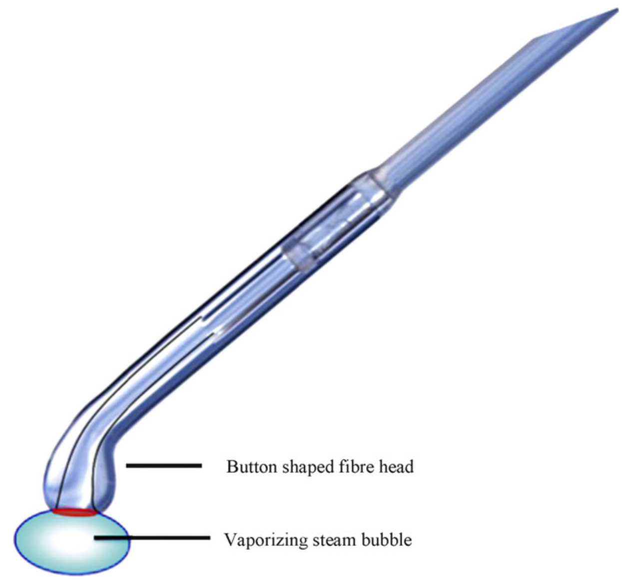

Fig. 5 – Twister fibre with steam bubble and button-shaped head. Courtesy of Biolitec, Jena, Germany.

are the limited lifespan, triggered by carbonisation at the laser beam output [7], leading to fibre damage and consequently to loss of efficacy [8,9]. As a possible solution, continuous flushing of the beam exit with irrigation fluid is realised in the MoXy fibre. By increasing the optical core diameter and the introduction of liquid cooling as well as a metal capping of the fibre tip, the lifespan of this side-fire fibre seems to be higher [10]. Although it is generally plausible to manufacture a MoXy-type side-firing fibre for all laser systems, the actual type is designed to be used only with the GreenLight XPS system.

In contrast to side-firing fibre systems, energy delivery via front-firing fibres is predominantly used for resection and enucleation. Laser radiation discharges from the tip directly into the tissue. By rapid heating of the tissue in a very small area, tissue effects such as vaporisation and disruption can be achieved.

Another approach called Twister fibre is utilised for contact laser vaporisation, as introduced by Biolitec for its laser system. In this fibre, the laser radiation is not released directly into the tissue but absorbed within the irrigation fluid, surrounding the fibre. A steam bubble in front of the fibre tip is thereby created, and vaporisation is achieved within the bubble and by the secondary heated button-shaped fibre tip (Fig. 5). To achieve this kind of vaporisation bubble, the laser radiation must be absorbed in the irrigation fluid, which is achieved by emission of laser radiation at 980 and 1470 nm.

3.2.3. Energy release

Depending on the mode of energy release (continuous wave vs pulsed wave), the effects of laser radiation on the tissue differ. Using a continuous wave laser and applying fluencies larger than the ablation threshold, the tissue is heated above the boiling point, causing vaporisation. By fibre movement over the tissue, a cutting effect can be achieved [11]. In pulsed laser radiation, the energy pulse is delivered via the fibre tip to the tissue. Laser radiation is delivered in short bursts with high-peak power, and a steam bubble is generated in front of the laser fibre with every pulse. This bubble mechanically separates tissue bridges. Confined ablation is realised during the pulse because of the rapid heating of the exposed tissue. Although different physical mechanisms appear, both mechanisms can be used to cut and coagulate the tissue [8].

By utilising the cutting effect, resection as well as enucleation can be performed (thulium laser vapoenucleation of the prostate [ThuVEP] [12], thulium laser vaporesection of the prostate [ThuVARP] [13], holmium laser resection of the prostate [HoLRP] [14], and holmium laser enucleation of the prostate [HoLEP] [15]).

3.3. Laser–tissue interaction

The principal light–tissue interaction encounters reflection, scattering, and reemission, which together result in photon and light distribution within the tissue and absorption by tissue chromophores. Light distribution and absorption affect the optical penetration in a wavelength-dependent manner (Table 2). For thermal laser–tissue effects, absorption is the most important factor [7].

Energy absorption leads to excitation of a molecule, which results in a temperature increase, and thus thermal effects appear. Thermal alteration may lead to coagulation, vaporisation, or carbonisation. To predict these effects, a number of variables are relevant including the wavelength and the type of radiated tissue, especially the amount of target chromophore. These variables define the effects of the laser radiation. Figure 6 displays the absorption coefficient of tissue chromophores (water and haemoglobin) in the wavelength range from 0.1 μm up to 100 μm, showing that the absorption of water ranged over eight orders of magnitude. Additionally, the optical penetration depth in the chromophore is displayed (right y-axis). In prostate tissue treatment, mainly two chromophores are of interest: the haemoglobin molecule in red blood cells and the intracellular water. Taking a given wavelength (eg, 500 nm; Fig. 6a), the absorption

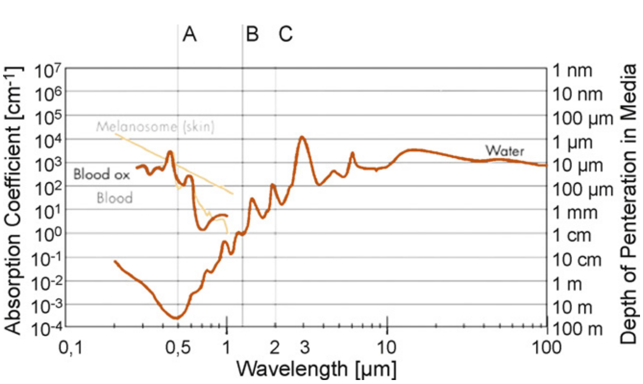

Fig. 6 – Absorption spectrum of prevailing body chromophores. Chromophore absorption at laser radiation of (a) 500 nm, (b) 1300 nm, and (c) 2000 nm.

coefficient and also the penetration depth depend on the type of radiated tissue. Because the laser wavelength is absorbed by red blood cells, the absorption coefficient is high, leading to shallow penetration of about 100 μm. In contrast, the same wavelength has a very low absorption coefficient in intracellular water, causing a penetration depth of approximately 30 μm.

Alternatively, one can take a given chromophore (eg, water) and examine absorption coefficient and optical penetration depth as a function of the utilised wavelength. The penetration depth in water at a wavelength of 1300 nm is within the centimetre range (Fig. 6b), whereas the penetration depth at a wavelength of 2000 nm is <500 μm (Fig. 6c). By considering the information presented in Figure 6, the laser–tissue effect of any given wavelength for the displayed chromophores blood and water can be estimated. Thus changing either wavelength or targeted tissue alters laser–tissue interaction.

After generating laser radiation and aligning it into tissue, it must be understood what happens with the radiated tissue. Once laser radiation is absorbed, optical energy is converted into thermal energy, resulting in increasing tissue temperature. The volume of heated tissue correlates with the absorption of the laser wavelength. Once the tissue is heated high enough to denaturise protein without reaching the boiling point, coagulation necrosis occurs. Continuous temperature increases above the boiling point lead to vaporisation [16]. However, laser–tissue interaction usually is a mixture of both. With any laser, heating of the targeted tissue causes vaporisation of a certain amount of superficial tissue once the critical boiling point is reached. Underneath this layer, tissue heats up but the temperature stays below the boiling point and causes coagulation necrosis. The combination of vaporisation and coagulation follows a simple principle: A high absorption coefficient within the targeted tissue confines the generation of heat to the surface of the tissue leading to a low penetration depth. Consequently, lasers emitting a wavelength with a high absorption coefficient predominantly affect the tissue surface. Providing sufficient laser power, the temperature of the irradiated tissue will increase rapidly above the boiling point. Only a small proportion of the delivered energy causes coagulation necrosis of the residual tissue. In contrast, laser light with a low absorption coefficient creates a deeper necrotic zone due to less concentrated energy absorption (Fig. 6). This effect was shown in ex vivo and in vivo studies. Below the vaporised area, coagulation necrosis with complete enzyme denaturation occurs, followed by an area with partly viable cells and partial enzyme denaturation. Below this, viable tissue can be found. The depth of these tissue effects reflects the penetration of laser radiation in tissue [12,17,18].

Once carbonisation occurs, there is no further optical penetration of the laser light. All energy is absorbed in the carbonised superficial layer, increasing the temperature locally and resulting in burn and burn ablation. Coagulation into depth occurs due to thermal heat transport. If burn-induced ablation is faster than the heat conductivity of the tissue, the thermal coagulation could be limited. If burn

Table 2 – Definitions in laser physics

Absorption coefficient	On entering into an absorbing medium, the intensity of the laser beam decreases exponentially (Lambert-Beer law). The absorption coefficient is a quantity that characterises how quickly the beam of a given laser would lose intensity due to the absorption alone in the selected medium. The absorption coefficient is expressed as units of reciprocal length (cm^{-1}).
Absorption length	The absorption length defines the optical pathway along which 1–1/e or 63% of the incident laser energy is absorbed.
Penetration depth	Penetration depth is often described by the extinction length (defined as the depth at which 90% of the incident laser beam is absorbed and is converted into heat). Extinction length is very important because a laser with shorter length transfers more energy per unit area into the tissue. This means that at the same power level, a laser wavelength with a long extinction length diffuses power delivered and creates a deep necrosis, whereas a laser wavelength with a much shorter extinction length allows a more concentrated delivery of light energy leading to an increase of temperature above boiling point and to immediate vaporisation of tissue.

ablation is slow, heat energy is conducted into the depth, thus inducing prominent coagulation areas.

3.4. *Translation into clinical practice*

In general, every reported approach of laser prostatectomy can be subdivided into three different principles (Table 3), independent of the laser type used. These principles are *vaporisation* (removal of the adenoma from the prostatic urethra to the surgical capsule), *resection* (excision of small tissue chips from the prostatic urethra to the surgical capsule), and *enucleation* (removal of the adenoma by cutting the layer of the surgical capsule and consecutive morcellation).

By knowing the basic principles of laser generation, delivery, and laser–tissue interaction, the appropriate laser as well as the optimal fibre can be chosen. If the surgeon's desire is to vaporise a prostate, a side-firing fibre may be advantageous because the energy can be easily delivered from the prostatic urethra to the adenoma. In contrast, in enucleation procedures the tip of the laser fibre mimics the index finger in open prostatectomy. In that case a front-firing fibre allows the tissue to be cut into the layer of the surgical capsule, moving in a retrograde manner from the verumontanum to the bladder neck.

Wavelength is another important factor. In enucleation procedures, the surgical site of action occurs at the pseudocapsule and thus close to the adjacent structures. A shallow penetration of laser radiation is necessary to control possible collateral damage. For example, in treating a patient with bleeding diathesis with a vaporising technique, the coagulation performance of the laser system is of utmost interest. In this case a laser system with either deeper penetration into the adenoma or energy absorption in haemoglobin may be beneficial because the longer distance to the pseudocapsule reduces the risk of injury to adjacent structures. Table 4 summarises laser systems with respect to wavelength and penetration depth.

Table 3 – Principles of laser prostatectomy and proper name

Laser prostatectomy		
Vaporisation	Resection	Enucleation
PVP	HoLRP	HoLEP
HoLAP	ThuVARP	ThuVEP
ThuVAP	Vaporesection	ThuLEP
Diode laser	Diode laser	GreenLEP
Vaporisation	Resection	Diode laser enucleation

PVP = photoselective vaporisation of the prostate; HoLRP = holmium laser resection of the prostate; HoLEP = holmium laser enucleation of the prostate; holAP = holmium laser ablation of the prostate; ThuVARP = thulium vaporesection of the prostate; ThuVEP = thulium vapoenucleation of the prostate; ThuVAP = thulium laser vaporesection of the prostate; ThuLEP = thulium laser enucleation of the prostate; GreenLEP = GreenLight laser enucleation of the prostate.

Table 4 – Wavelength and penetration depth of laser systems for treatment of benign prostatic obstruction

Laser device	Wavelength, nm	Optical penetration depth in target chromophore, mm
KTP/LBO	532	0.8
Diode	940, 980, 1318, 1470	0.5–5 mm
Nd:YAG	1064	10
Thulium	1940/2013	0.2
Holmium:YAG	2100	0.4

KTP = potassium-titanyl-phosphate; LBO = lithium triborate; Nd = neodymium; YAG = yttrium-aluminium-garnet.

3.4.1. *Lasers typically used for vaporisation*

3.4.1.1. GreenLight laser. The GreenLight laser emits laser radiation at a wavelength of 532 nm. The tissue target chromophore is the haemoglobin molecule, which has a very high absorption coefficient at this wavelength (Fig. 6). Laser radiation into the tissue is delivered using a side-firing fibre. In general, this laser is used with good results in pure vaporisation techniques, although enucleation procedures were reported recently [19–22].

3.4.1.2. Diode lasers. There is not a unique diode laser. The term *diode laser* defines a group of lasers using a semiconductor bar to generate laser radiation. By using different semiconductor elements and layer structures, the generation of various wavelengths is possible (Table 1), thus providing laser systems emitting at 940, 980, 1318, and 1470 nm. Reviewing laser–tissue interaction and Figure 6, it becomes clear that different wavelengths must be judged independently. The target chromophore differs depending on wavelength. Compared with the GreenLight LBO laser, different diode laser systems showed comparable or superior tissue ablation rates and lower bleeding rates. However, tissue necrosis and penetration depth were significantly higher [20,23,24]. Clinical trials showed significant early improvement in the International Prostate

Table 5 – Clinical data for laser devices

	No. of patients included	Range of follow-up, mo	Range of mean volume, cm^3	Range of PSA reduction, %	Range of symptom improvement, %	Range of Q_{max} improvement, ml/s	Range of PVR reduction, %	Level of evidence
Vaporising techniques								
GreenLight (532 nm: KTP/LBO)	242	6–36	42.4–108.4	31.8–61.2	30.1–82.6	5.8–13.5	78.9–87.5	1B
Diode (1470 nm)	10	12	47.8	42	64.3	13.5	88.9	3B
Diode (980 nm)	212	6–12	51.4–66.3	30.3–58.8	54.9–84.2	5.1–14	58.1–87.7	1B/3B
Enucleating techniques								
HoLEP (2100 nm)	582	12–72	53.5–114.6	81.7v86 [41]	61–92	10.9–23.6	83–98	1B
ThuVEP (Tm:YAG 2013 nm)	140	6–18	40.3–61.3	80	63–70	14.9–15.7	72.4–80	1B/2B

PSA = prostate-specific antigen; Q_{max} = maximum flow rate; PVR = postvoiding residual; KTP = potassium-titanyl-phosphate; LBO = lithium triborate; HoLEP = holium laser enucleation of the prostate; ThuVEP = thulium vapoenucleation of the prostate; Tm:YAG = thulium:yttrium-aluminium-garnet.
Adapted and modified from Herrmann et al. [40].

Symptom Score and urinary flow rates, combined with high intraoperative safety. A relatively high number of dysuria and retreatment rates were reported in a single series and need further evaluation [25–28].

3.4.2. Lasers typically used for resection/enucleation

3.4.2.1. Thulium lasers. Two types of thulium lasers have been introduced in the treatment of BPO. Both use a wavelength around 2000 nm (Tm:YAG laser [Revolix], 2013 nm, and Tm-fibre laser [Vela XL], 1940 nm) for laser radiation. The target chromophore is water, with radiation emission in a continuous wave mode. Due to the shallow optical penetration of approximately 0.2 mm, radiated tissue is rapidly vaporised [29]. The side-fire technique is available, but published applications of the thulium:YAG laser are mainly resection and enucleation procedures using front-firing fibres. Due to the high proportion of vaporisation during these procedures, the terms *vaporesection* and *vapoenucleation* have been introduced. Clinical data of the Tm:YAG laser suggest a high safety profile and effectiveness at intermediate-term follow-up [14,15,30–32]. Clinical data on the newer Tm-fibre laser are pending.

3.4.2.2. Holmium:YAG lasers. The Ho:YAG laser operates at 2100 nm, using water as the chromophore. Laser radiation is emitted in a pulsed mode and several kilowatt pulse peak power. Due to the wavelength and the short high-peak power laser pulses, high-energy concentration can be achieved with each pulse, resulting in vigorous expanding and collapsing steam bubbles within the duration of the laser pulse. These steam bubbles create disruptions of prostatic tissue that are utilised for surgical effects. As the laser that has the longest postlaunch time, multiple surgical techniques have been introduced, including ablation, resection, and enucleation. Enucleation (HoLEP) is the main field of application today for the Ho:YAG laser in BPO. Using the pulsed energy release, the laser can be used like a chisel to enucleate enlarged prostatic tissue at the layer of the surgical pseudocapsule. In general, HoLEP is mimicked by all recently introduced enucleation procedures and modified according to the properties of the particular laser. Ho:YAG laser enucleation has proven to be efficacious and safe in multiple trials and represents the reference method for all newly introduced laser-based enucleation procedures [17,33–39].

In vaporisation, the GreenLight laser has been studied the most intensively; data on diode laser systems were published recently. If resection, and especially enucleation-like procedures are planned, Ho:YAG and thulium laser systems may be the system of choice because they are optimised for that technique, emitting laser radiation at the 2-μm wavelength with shallow penetration in a front-firing mode. HoLEP has proven its efficiency in long-term follow-up, whereas long-term data for the newer thulium devices are still pending. Table 5 summarises the published clinical data for these laser devices. Independently of the laser system used, bleeding complications are significantly reduced in laser-based procedures, and the TURP syndrome is ruled out due to the use of normal saline.

3.5. Summary

Although they are summarised using the acronym *laser*, available systems for the treatment of BPO diverge in the type of laser energy generation, laser radiation delivery, and interaction with the desired target tissue. Knowledge of the factors reviewed in this paper is mandatory for the surgeon to choose the correct surgical laser and approach for individual patients. The most important factors to differentiate laser-based procedures are wavelength, fibre type, and surgical technique. One must keep in mind that deeper penetration depth leads to a higher rate of coagulation and a lower proportion of vaporisation. Deep penetration of tissue may lead to excellent haemostasis but also to a deeper area of necrotic tissue with the risk of undesired side effects in the sphincter muscle or the neurovascular bundles. Shallow penetration means high-energy absorption in a very defined volume. The accompanied coagulation zone is superficial, allowing easier control of the area of laser–tissue interaction. In terms of the surgical approach, laser enucleation in particular has proven to be a size-independent transurethral procedure, challenging the role of open prostatectomy with equal efficiency and significantly reduced morbidity. Vaporising procedures seem to be advantageous in patients undergoing anticoagulation or with prostate glands of low to intermediate volume.

4. Conclusions

Although laser treatment of BPO has gained widespread acceptance, controversy continues about the physical properties and background of laser radiation generation and laser–tissue interaction. Knowledge about the effects of different wavelengths on the targeted tissue is mandatory. The term *laser prostatectomy* should only be mentioned in combination with laser type or wavelength. Available laser systems have proven clinical efficacy comparable with the well-established gold standard. Knowledge of the physical effects of the different laser systems discussed in this paper helps the surgeon offer the best and least invasive therapy to all patients, independent of possible comorbidities or prostate size. Transurethral laser enucleation in particular offers a safe and effective minimal invasive treatment for patients with larger prostates and thus makes the need for open prostatectomy at least debatable.

Due to the nature of laser physics, it is unlikely that future research will lead to tuneable laser systems offering wavelength modifications for every indication. However, combined laser systems offering various laser sources operated in a single device may be an option, allowing the surgeon to offer tailored techniques to every patient.

Author contributions: Jens J. Rassweiler had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Acquisition of data: Bach, Muschter, Sroka, Gravas, Skolarikos, Herrmann, Bayer, Knoll, Abbou, Janetschek, Bachmann, Rassweiler.
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Critical revision of the manuscript for important intellectual content: Bach, Muschter, Sroka, Gravas, Skolarikos, Herrmann, Bayer, Knoll, Abbou, Janetschek, Bachmann, Rassweiler.
Statistical analysis: None.
Obtaining funding: None.
Administrative, technical, or material support: None.
Supervision: Rassweiler.
Other (specify): None.

Financial disclosures: I certify that all conflicts of interest, including specific financial interests and relationships and affiliations relevant to the subject matter or materials discussed in the manuscript (eg, employment/affiliation, grants or funding, consultancies, honoraria, stock ownership or options, expert testimony, royalties, or patents filed, received, or pending), are the following: None.

Funding/Support and role of the sponsor: The following companies provided unrestricted educational support: American Medical Systems, Biolitec, Dornier, Karl Storz, LISA laser, Lumenis, Rolle & Rolle, Richard Wolf, and Starmedtec.

References

[1] Rassweiler J, Teber D, Kuntz R, Hofmann R. Complications of transurethral resection of the prostate (TURP)—incidence, management, and prevention. Eur Urol 2006;50:969–80.
[2] Tubaro A, de Nunzio C. The current role of open surgery in BPH. EAU-EBU Update Series 2006;4:191–201.
[3] Reich O, Gratzke C, Bachmann A, et al. Urology Section of the Bavarian Working Group for Quality Assurance. Morbidity, mortality and early outcome of transurethral resection of the prostate: a prospective multicenter evaluation of 10654 patients. J Urol 2008;180:246–9.
[4] Gratzke C, Schlenker B, Seitz M, et al. Complications and early postoperative outcome after open prostatectomy in patients with benign prostatic enlargement: results of a prospective multicenter study. J Urol 2007;177:1419–22.
[5] Adam C, Hofstetter A, Deubner J, et al. Retropubic transvesical prostatectomy for significant prostatic enlargement must remain a standard part of urology training. Scand J Urol Nephrol 2004;38: 472–6.
[6] Einstein A. Zur Quantentherorie der Strahlung. Physikalische Zeitschrift 1917;18:121–8.
[7] Teichmann HO, Herrmann TR, Bach T. Technical aspects of lasers in urology. World J Urol 2007;25:221–5.
[8] Nazif OA, Teichman JMH, Glickman RD, Welch AJ. Review of laser fibers: a practical guide for urologists. J Endourol 2004;18:818–29.
[9] Hermanns T, Sulser T, Fatzer M, et al. Laser fibre deterioration and loss of power output during photo-selective 80-W potassium-titanyl-phosphate laser vaporisation of the prostate. Eur Urol 2009;55:679–86.
[10] Bachmann A, Ruszat R, Wyler S, et al. Photoselective vaporization of the prostate: the Basel experience after 108 procedures. Eur Urol 2005;47:798–804.
[11] Te AE. The next generation in laser treatments and the role of the GreenLight High-Performance System Laser. Rev Urol 2006;8 (Suppl 3):S24–30.
[12] Malek RS, Kang HW, Peng YS, Stinson D, Beck MT, Koullick E. Photoselective vaporization prostatectomy: experience with a novel 180 W 532 nm lithium triborate laser and fiber delivery system in living dogs. J Urol 2011;185:712–8.
[13] Muschter R, Perlmutter AP. The optimization of laser prostatectomy II: other techniques. Urology 1994;44:856–61.
[14] Bach T, Netsch C, Haecker A, Michel MS, Herrmann TRW, Gross AJ. Thulium laser enucleation (VapoEnucleation) of the prostate: safety and durability during intermediate-term follow-up. World J Urol 2011;28:39–43.
[15] Bach T, Herrmann TR, Ganzer R, Burchardt M, Gross AJ. RevoLix vaporesection of the prostate: initial results of 54 patients with a one-year follow-up. World J Urol 2007;25:257–62.
[16] Westenberg A, Gilling P, Kennett K, Frampton P, Fraundorfer M. Holmium laser resection of the prostate versus transurethral resection of the prostate: results of a randomized trial with 4-year minimum long-term followup. J Urol 2004;172:616–9.
[17] Krambeck AE, Handa SE, Lingeman JE. Experience with more than 1000 holmium laser prostate enucleations for benign prostatic hyperplasia. J Urol 2010;183:1105–9.
[18] Gravas S, Bachmann A, Reich O, Roehrborn CG, Gilling PJ, de la Rosette J. Critical review of lasers in benign prostatic hyperplasia (BPH). BJU Int 2011;107:1030–43.
[19] Bach T, Huck N, Wezel F, Häcker A, Gross AJ, Michel MS. 70 vs. 120 W thulium:yttrium-aluminium-garnet 2 μm continuous-wave laser for the treatment of benign prostatic hyperplasia: a systemic ex-vivo evaluation. BJU Int 2010;106:368–72.
[20] Seitz M, Bayer T, Ruszat R, et al. Preliminary evaluation of a novel side-fire diode laser emitting light at 940 nm, for the potential treatment of benign prostatic hyperplasia: ex-vivo and in-vivo investigations. BJU Int 2009;103:770–5.
[21] Malek RS. GreenLight™ HPS laser therapy for BPH: clinical outcomes and surgical recommendations from the International GreenLight User (IGLU) Group. Eur Urol Suppl 2008;7:316–62.

[22] Kang HW, Jebens D, Malek RS, Mitchell G, Koullick E. Laser vaporization of bovine prostate: a quantitative comparison of potassium-titanyl-phosphate and lithium triborate lasers. J Urol 2008;180: 2675–80.

[23] Malek RS, Kuntzman RS, Barrett DM. Photoselective potassium-titanyl-phosphate laser vaporization of the benign obstructive prostate: Observations on long-term outcomes. J Urol 2005;174: 1344–8.

[24] Woo H, Reich O, Bachmann A, et al. Outcome on GreenLight HPS 120-W laser therapy in specific patient populations: those in retention, on anticoagulants, and with large prostates (≥80 ml). Eur Urol Suppl 2008;7:378–83.

[25] Wezel F, Wendt-Nordahl G, Huck N, et al. New alternatives for laser vaporization of the prostate: experimental evaluation of a 980-, 1318- and 1470-nm diode laser device. World J Urol 2010;28:181–6.

[26] Seitz M. Ex vivo and in vivo investigations of the novel 1,470 nm diode laser for the potential treatment of benign prostatic enlargement. Lasers Med Sci 2009;24:419–24.

[27] Ruszat R, Seitz M, Wyler SF, et al. Prospective single centre comparison of a 120-W diode-pumped solid-state high intensity system laser vaporization of the prostate and a 200-W high-intensive diode-laser ablation of the prostate for treating benign prostatic hyperplasia. BJU Int 2009;104:820–5.

[28] Seitz M, Sroka R, Gratzke C, et al. The diode laser: a novel side-firing approach for laser vaporisation of the human prostate—immediate efficacy and 1-year follow-up. Eur Urol 2007;52:1717–22.

[29] Erol A, Cam K, Tekin A, Memik O, Coban S, Ozer Y. High power diode laser vaporization of the prostate: preliminary results for benign prostatic hyperplasia. J Urol 2009;182:1078–82.

[30] Chen CH, Chiang PH, Chuang YC, Lee WC. Preliminary results of prostate vaporization in the treatment of benign prostatic hyperplasia by using a 200-W high intensity diode laser. Urology 2010;75: 658–63.

[31] Wendt-Nordahl G, Huckele S, Honeck P, et al. Systemic evaluation of a recently introduced 2 μm continuous wave thulium laser for vaporesection of the prostate. J Endourol 2009;103: 770–5.

[32] Xia S-J, Zhuo J, Sun X-W, Han B-M, Shao Y, Zhang Y-N. Thulium laser versus standard transurethral resection of the prostate: a randomized prospective trial. Eur Urol 2008;53:382–90.

[33] Szlauer R, Götschl R, Razmaria A, Paras L, Schmeller NT. Endoscopic vaporesection of the prostate using the continuous wave 2-μm thulium laser: outcome and demonstration of the surgical technique. Eur Urol 2009;55:368–75.

[34] Bach T, Xia SJ, Yang Y, et al. Thulium:YAG 2 μm cw laser prostatectomy: where do we stand?. World J Urol 2010;28:163–8.

[35] Tooher R, Sutherland P, Costello A, Gilling P, Rees G, Maddern G. A systemic review of holmium laser prostatectomy for benign prostatic hyperplasia. J Urol 2004;171:1773–81.

[36] Naspro R, Suardi N, Salonia A, et al. Holmium laser enucleation of the prostate versus open prostatectomy for prostates >70 g: 24-month follow-up. Eur Urol 2006;50:563–8.

[37] Kuntz RM, Lehrich K, Ahyai SA. Holmium laser enucleation of the prostate versus open prostatectomy for prostates greater 100 grams: 5-year clinical follow-up results of a randomised clinical trial. Eur Urol 2008;53:160–8.

[38] Gilling PJ, Aho TF, Frampton CM, King CJ, Fraundorfer MR. Holmium laser enucleation of the prostate: results at 6 years. Eur Urol 2008;53:744–9.

[39] Elzayat EA, Elhilali EM. Holmium laser enucleation of the prostate (HoLEP): long-term results, reoperation rate, and possible impact of learning curve. Eur Urol 2007;52:1465–72.

[40] Herrmann TR, Liatsikos E, Nagele U, Traxer O, Merseburger AS. Guidelines on lasers and technology. European Association of Urology Web site. http://www.uroweb.org/gls/pdf/24_Lasers%20and%20Technologies.pdf.

[41] Tinmouth WW, Habib E, Kim SC, et al. Change in serum prostate specific antigen concentration after holmium laser enucleation of the prostate: a marker for completeness of adenoma resection? J Endourol 2005;19:550–4.