doi: 10.20903/zpopov-2022-0019 UDK: 616.65-007.61-085.849.19

Dragoslav BAŠIĆ[2]

LASER THERAPY FOR BENIGN PROSTATIC HYPERPLASIA: PHYSICAL BASICS AND CURRENT STATUS

Abstract

Introduction: Contemporary laser technologies in urology are becoming a new gold standard and a necessary tool for minimally invasive treatment of benign prostatic hyperplasia (BPH). Advances in laser technology applied to the treatment of BPH have been inspired primarily by the need to find a comparable alternative therapeutic option to transurethral resection of the prostate (TURP) and open prostatectomy (OP).

Material and methods: Laser procedures for BPH encompasses a variety of laser types and operative techniques, including visual laser ablation of the prostate (VLAP), transurethral ultrasound guided laser incision prostatectomy (TULIP), potassium titanyl phosphate (KTP) laser, contact laser vaporization of the prostate (CLV), interstitial laser coagulation (ILC), holmium laser resection of the prostate (HoLRP), holmium laser enucleation of the prostate (HoLEP), holmium laser ablation of the prostate (HoLAP) and thulium laser (vapo)enucleation or resection. Each of these techniques has certain advantages and disadvantages, both when compared with each other, and when compared to TURP.

Results: Modern lasers have far greater energy power compared with the older generations of lasers, and these modern lasers are used in surgery for precise cutting, evaporation and tissue coagulation. The effect of the laser depends on the wavelength as well as on the ability of the target tissue to absorb radiation energy. Thus, to choose the best laser for a given type of surgery, one should keep in mind the differences between lasers, the

---

[2] Clinic of Urology, University Clinical Center Niš, Niš, Serbia Faculty of Medicine, University of Niš, Niš, Serbia; basicdr@gmail.com

variability of their use, and the factors that determine how the laser affects the tissue. The aspirations of this study were aimed at creating innovative procedures, which would not have limitations in terms of prostate volume and whose clinical results related to perioperative morbidity, hemorrhage and hospitalization period would be at least identical to the clinical results achieved by the TURP and OP.

Conclusions: Traditional operating techniques are slowly becoming a thing of the past, and classical methods are being replaced by technological innovations, primarily advanced lasers. Among the many types of lasers used for the surgical treatment of BPH, the holmium and thulium lasers are currently the most widely used in clinical practice.

INTRODUCTION

In the last few decades, there has been intensive development in the field of laser construction, such that the knowledge gained by modern physics finds wide applications in various fields of science and technology. All the advantages of the phenomenon of laser light emission are compatible with the needs of practical medicine, especially surgical branches. A large number of scientific and professional papers in this field testify to the expansion of this relatively young discipline of scientific knowledge and how it is applied in the field of biomedicine. Scientific progress in the field of laser medicine is accompanied by the production of adequate laser medical equipment. Modern lasers represent a synthesis of the most modern achievements of quantum electronics, precision mechanics, optics, and electrical engineering. Laboratory and clinical research have resulted in the understanding of a number of advantages of laser techniques over classical methods. These advantages include: ease of handling, low risk of intervention, non-contact of tissue manipulators, precise tissue destruction, access to inaccessible organs and tissues, minimal damage to surrounding healthy tissue, absence of side effects (bleeding, pain, infection), rapid wound healing, possibility repetitions of the procedure, etc.

The word laser comes from the initial letters of the English name: Light Amplification by Stimulated Emission of Radiation (1). This name contains two important physical characteristics that explain this special way of obtaining light, and which, both in the recent past and today, are in the center of interest of almost all modern scientific branches, especially medicine and biology. Laser light emission is a quantum phenomenon and its origin is based on the laws of quantum physics, i.e. the interaction of photons with matter. The absorption coefficient can be considered negative, which means that the light intensity increases. More precisely, the laser is not a light amplifier, but a kind of oscillator that generates light, i.e. represents a light source.

Another phenomenon we encounter here is stimulated radiation emission. It is interesting that in 1917, Albert Einstein predicted the possibility of such a show, and that the laser was realized only in 1960. The principle of stimulated radiation was first used in the generation of microwaves (masseurs) (2).

Laser-tissue interaction

The application of laser as a method and means in medicine for the treatment of many diseases, will be much clearer if the reaction of tissues to laser radiation is explained. In fact, there is a laser-tissue interaction, which results in functional, structural and biochemical changes that occur in the body as a result of irradiation. At the very beginning of the development of laser technology, the essential importance of laser-tissue interaction was noticed, and then tests in developed countries showed that laser radiation is, in fact, an artificial physical agent, and its effects on living organisms depend on laser emission parameters and physiological properties, irradiated tissue. To explain the reaction of laser radiation on biological tissues, a multidisciplinary approach is necessary in the further study of this phenomenon, i.e. the application of methods that are primarily based on the principles of biology and physics. There is no doubt that there are positive therapeutic effects based on these mechanisms, but further scientific clarification of the interaction of laser radiation with bio tissues is necessary, along with monitoring the input values in the interaction, i.e. laser output parameters, on the one hand, and the results of the total effect of laser radiation on health, on the other (3).

Factors of laser energy action on biological tissues can be classified thus: thermal, photochemical, electrical, mechanical, quantum and multiphonic effects, which result in local increase of pressure, temperature and photobiological reactions in irradiated tissues. Not only the parameters of laser radiation (laser type, wavelength, radiation power density, pulse frequency, etc.), but also the physiological characteristics of irradiated tissues and organs (blood flow intensity, thermal conductivity, absorption and reflection coefficient, heterogeneity, microstructure, etc.) determine the final the result of the biological effect of laser radiation on biological objects.

Biogenic effects resulting from the laser-tissue interaction can be conditionally divided into three basic categories:

- Primary effects (change of global energy of electronic levels of mercury and the matter of the molecules, restructuring of living matter molecules, coagulation of protein structures);
- Secondary effects (photodynamic effect, photoreactivation effect, stimulation of bioprocesses);
- Tertiary effects, so-called subsequent effects (elastic oscillations of molecules protein, formation of toxic products in tissues, etc.).

When analyzing secondary effects, it is necessary to take into account the corrections of the state of biological systems related to nonlinear optical effects, electrostriction, acoustic and ultrasonic oscillations and standing waves. Little is known about these significant factors and there is little data in the literature. Due to the generation II harmonics, which represent radiation with new parameters, nonlinear optical effects are related to tissue excitation. Tissues that are irradiated with infrared light begin to emit green light. Addition, subtraction and frequency eruptions may also occur (3). The effect of electrostriction results in deformations and probably, destruction of macromolecules of living matter. When the state of protein structures (colloidal changes) of irradiated tissues changes, acoustic, ultrasonic oscillations, and standing waves appear, which are all resonant processes. Secondary effects are actually a complex of reactions in the organism and are correlated with the primary effects that are responsible for the immediate changes in the tissues.

Having in mind the existence of many different factors that are at play in the creation of appropriate biogenic effects, researchers encounter complex systems, diverse in nature, with a consequent series of events that take place in the irradiated part of the organism. All this is part of an integral picture of the final effects of the interaction of laser radiation within living systems. The integrity of such a picture, however, cannot exclude the dominance of one of the above components of interaction over another, which depend on the character of the biological object and laser parameters.

Low and moderate power densities of laser radiation (10-103 Wcm-2) lead to an increase in tissue temperature (photothermal action), or initiate chemical reactions (photochemical action). A moderate increase in temperature (up to 10 ° C) causes coagulation of molecules in the tissue and therefore a visible thermal reaction (photocoagulation) occurs. A further increase in temperature causes evaporation of intracellular and extracellular fluid (water) and makes an incision in the tissue (photovaporization). By injecting certain substances, it is possible to make the tissue sensitive to a certain wavelength, and when such tissue is irradiated with laser light of the same wavelength, destructive free radicals (photoradiation) are created. The excimer laser emits in the UV (ultraviolet) region of the spectrum, so that the initiated photochemical reaction breaks the molecular bond in the tissue, which can create precise defects in the tissue, without heat damage, which is removed by molecule fragments (ablative photodecomposition).

Short-term pulses (30ps-15ns), high power density (1010 Wcm-2) generated by a Nd: YAG laser, cause the breakdown of electrons in tissue molecules and thus lead to ionization of molecules and tissue disintegration. Additional destruction of the target tissue is achieved by the rapid expansion of the resulting plasma, which creates a mechanical wave. By absorbing or scattering each subsequent pulse of the laser beam, the plasma protects the tissue behind the target. This process is called photodisruption. A laser is a powerful beam of radiation that produces predominant thermal damage in the target tissue. Each type of laser produces a beam of one wavelength or at most two similar wavelengths. The effect of the laser depends on the wavelength, as well as on the ability of the target tissue to absorb radiation energy. Thus, to choose the best laser for a given type of surgery, one should keep in mind the differences between lasers, the variability of their use and the factors that determine how the laser affects the tissue. In general, only two types of lasers are important for medical and dental use. These are "soft" (low-energy) lasers, so thermal effects are excluded and their main purpose is to stimulate cellular activity; the second type are "hard" lasers, which are dominated by thermal effects and are used in surgery for precise cutting, evaporation (evaporation, evaporation) and tissue coagulation (4,5).

Physical principles of laser operations

The laser beam is unique in existence, composed of photons of the same wavelength, which travel in phase and parallel to each other. The radiation is emitted from an active medium-substance composed of atoms, which, when excited, emit radiation of a usable wavelength. In order to achieve light amplification, the active medium must first be supplied with some form of energy (light, heat, electricity), so that a large number of atoms absorb enough energy to pass into the excited state. At this point, spontaneous photon emission begins to take place, as some of the excited atoms return to their previous state. When each type of active medium is excited to a certain energy state and spontaneously emits excess energy, photons with a wavelength characteristic of that medium are released. The stimulated emission originates from the moment when one emitted photon collides with one excited atom, which has absorbed an amount of energy equal to that of the photon, which, colliding with that atom, causes the emission of a photon from it. When both photons have the same wavelength, they are in phase, and they leave the atom going in the same direction. Amplification occurs by striking a certain number of photons back and forth through an active medium between two mirrors placed both below and above the medium. The mirror at the output end is partially reflective, so that it transmits a certain proportion of photons, directing them like a laser beam, while the others are reflected back into the active medium to continue stimulating the release of other photons from the excited atoms. The mirror at the other end reflects 100% of the photons, directing them back to the partially reflecting mirror at the output end. In this way, a certain percentage of the created photons strike back and pass between the two mirrors at the speed of light, stimulating the emission of photons from the excited atoms. The laser beam is monochromatic, coherent and very intense. It is created as a result of the stimulated emission of the amplification process. The coherent nature of the beam allows it to be focused by the lens at points, whose radius can theoretically be equal to half the wavelength of the beam. All photons from a ray can be compressed into a very tiny point, resulting in the flux or number of photons passing through that point at the same time. This means that the laser beam can be used to concentrate energy and deliver it in extremely high doses to the target area, even to a very small area (6,7).

Air power. Power density

The power of a laser beam is the property of the beam to transmit energy to a specific target point in a unit of time and thus increase the vibrational motion of the target atoms and molecules. Power density (PD) is the amount of power per area and is calculated by dividing the power (W) emitted by the laser, by the area of the target point. PD = W / πr2 (r-radius of the circle), which shows that PD varies inversely with the square of the radius of the point. It is important that the surgeon knows and intuitively understands how strength density affects the tissue. First, the level of ablation varies with power density. Higher power density means faster ablation. Second, the zone of thermal damage below the tissue surface varies depending on the strength density. At low power density values, the tissue heats up more slowly and has time for the heat to be conducted to the layers that lie below the actual layer. When the PD value is high, the surface tissues heat up rapidly to the boiling point of intracellular water, when a large part of the air energy is dissipated in the form of water vapor, which partially carbonizes the organic cellular components. The rest of the heat is conducted to the lower layers, but because this process is relatively slow to evaporate, the heat does not penetrate long before the evaporation field reaches the zone of thermal damage. Thus, at lower power density values, the zone of thermal damage below the tissue surface increases. Conversely, at high strength density values, the zone of thermal damage below the tissue surface decreases (4,8).

CW and pulsed lasers

There are two basic ways of delivering energy for any type of laser, and they are pulsed and continuous wave. The continuous wave (CW) is the same as with a flashlight; the intensity of light, in a unit of time, is constant. Pulsed lasers are similar to stroboscopic light: energy is delivered through a series of intense flashes with a very short duration (ms, ns). As with stroboscopic light, if the pulses (oscillations) are delivered in high doses, they can make the air look continuous, but the key difference is that the rate of energy transfer during the pulse is much higher than the rate at which the CW laser transmits energy during the same time period. Maximum power indicates the maximum value of energy transfer during the pulse. The pulsation of the laser beam can be performed in two different ways: either by transmitting activation energy to the active medium in pulses, or by a process called Q-switching. Q-switching is performed by introducing a fast shutter between the active medium and the output mirror. By simultaneously holding the shutter closed and pumping the activation energy into the active medium, the activation energy is "captured" as a photon within the active medium. Thus, there is an extremely large increase in energy in the active medium. When the shutter opens, that energy is released almost instantly, and as a result, the peak of the pulse energy is high. Q-interruption is common for industrial lasers, but is not widely used for medical lasers, except in the fragmentation of ureteral calculi. The main limiting factor is the conduction of laser energy through the optical fibers. The energy flux at the input to the optical fiber exceeds the damage threshold of the fibrous material even at wavelengths that are easily transmitted by the CW mode. Storz introduced the Q-switching Nd: YAG (neodymium: yttrium-aluminum-garnet) laser, which is capable of fiberoptic transmission and is good for endoscopic lithotripsy (stone breaking) in medicine.

Advances in laser technology applied in the treatment of BPH have been inspired primarily by the need to find a comparable alternative therapeutic option to transurethral resection of the prostate (TURP). Aspirations were aimed at creating innovative procedures, which would not have limitations in terms of prostate volume and whose clinical results, related to perioperative morbidity, hemorrhage, and hospitalization period, would be at least identical to the clinical results achieved by the TURP procedure. In the early 1990s, Nd: YAG visual prostate ablation (VLAP) and Nd: Yag interstitial laser coagulation (ILC) of the prostate were enthusiastically used. The results of these procedures were shown to be significantly weaker in relation to TURP, both in relation to urination parameters and in relation to the rate of reinterventions and reoperations. As a result, these procedures were abandoned. Later, through the framework of the stated needs, the following types of lasers were reviewed for their use: Neodymium: yttrium aluminum garnet (Nd: YAG), Holmium (Ho): YAG and Nd: Yag (Potassium titanyl phosphate) (KTP) laser. Each of these lasers acts at a different wavelength, and the effects in the tissue are achieved by heating, the degree and speed of which depend on the immediate surgical effects. Modern lasers have far greater energy power compared to older generations of lasers (9,10).

Th Nd: YAG (Neodymium: Yttrium Aluminum Garnet) laser

The beam wavelength of Nd: YAG lasers is 1064 nm, close to the infrared spectrum. The air is invisible and achieves a tissue penetration depth of about 10 mm. Due to the action of this laser, an increase in temperature occurs in the tissue, which causes coagulation necrosis. Therefore, the resection and hemostasis characteristics of this laser are good and are useful for soft tissue incision (urethral stenosis, ureteral stenosis, bladder neck sclerosis), tissue ablation (BPH) and skin changes (condyloma, penile cancer). Alternatively, the contact technique achieves the effects of tissue vaporization (11,12).

Holmium: YAG (Holmium: yttrium aluminum garnet) laser

This type of laser emits a wavelength of 2100nm, with a high coefficient of absorption in water. It is used primarily in pulse mode, rarely in continuous. Its absorption length in prostate tissue is short (0.4 mm), which provides excellent characteristics for vaporization. In addition, damage to the surrounding racetrack is minimal (0.5-1mm). It is used for prostate enucleation in BPH and lithotripsy. There are numerous lasers of this type in use, and each type operates at a different wavelength (12).

KTP (Potassium Titanyl Phosphate) laser

The potassium-titanyl phosphate (KTP) laser beam is in the region of the visible green spectrum, with a wavelength of 532 nm. It occurs as a consequence of the passage of Nd: YAG-waves (1064 nm) through the KTP crystal, which doubles the frequency and halves the wavelength. The actions of this laser are similar to the actions of an argon laser, with a maximum power of about 60W. The absorption characteristics of KTP lasers are good for the effects of vaporization, coagulation and hemostasis (10).

PVP (Photoselective vaporization of the prostate)

The potassium-titanyl phosphate (KTP) laser beam is in the region of the visible green spectrum, with a wavelength of 532 nm. The absorption characteristics of KTP lasers are good for the effects of vaporization, coagulation, and hemostasis. When using high power, the action of this laser in the prostate tissue causes photothermal vaporization of intracellular tissue water, which is used in a procedure known as photoselective vaporization of the prostate (PVP). Because KTP energy is strongly absorbed by hemoglobin, tissue penetration is less pronounced. The hemostatic characteristics of this laser are extraordinary, while the zone of coagulation necrosis is only 2 mm, which achieves a vaporization coefficient of 0.3-0.5 g / min. As such, it is possible to achieve a reduction in prostate volume of up to 43%, which has been shown to be sufficiently effective for acute deconstruction, even in patients using oral anticoagulant therapy. A good feature of this laser is the possibility of changing the air pressure during work. This is useful considering that the lateral lobes of the prostate are more adenomatous, while the medial lobe has a pronounced muscular-collagen structure. The disadvantage of this method is that it does not provide a sample of prostatic tissue for PH analysis. The 80W KTP laser and the 120W KTP laser are the two current KTP laser models on the market.

Although long-term results are not yet available, published results of one-year follow-ups of patients undergoing PVP with KTP laser 80W show that compared to TURP, PVP is associated with uniform parameters of micturition and IPSS score, lower blood loss and shorter catheterization and hospitalization periods. The rate of early postoperative complications is low and comparable with HoLEP and TURP results. Some authors report a slightly higher rate of urethral stenosis (7%).

The new 120W KTP HPS (high performance system) laser was developed with the aim of increasing the vaporization coefficient and shortening the operation time. It includes a lithium borate laser. Despite the acceleration of the vaporization effect, the high power of this laser poses a potential danger that, due to increased depth of penetration and reduced vision (more bubbles in the field of view), perforation of the prostate capsule, bladder perforation and ureteral orifice injuries can occur, especially when the medial lobe is pronounced. The results of a five-year follow-up of patients who underwent PVP KTP with a 120W laser show a significant improvement in key parameters (AUA-symptom score, maximum urine flow, post-micturition residual urine, prostate volume), without statistically significant differences in relation to TURP (11-15).

Holmium laser enucleation of the prostate (HoLEP)

Except for prostate volume, all remaining indications for surgical treatment of BPH with this procedure are identical to indications for transurethral resection (TURP). In relation to prostate volume, indications for HoLEP include larger prostates, even up to 200ml. Exclusion criteria are urination disorders that are not caused by benign prostatic hyperplasia, previous surgical interventions on the prostate, bladder neck or urethra, as well as the existence of prostate cancer. According to the published results of randomized studies, the rate of perioperative morbidity is very low, with slight blood transfusions, the absence of TUR syndrome and the need for reintervention. The rate of postoperative urinary retention ranges up to 8%. The occurrence of possible postoperative dysuria or urgent incontinence (1%) is usually resolved with drug therapy in a shorter period of time. In large series, the incidence of urethral stenosis after the procedure is stated to be 1.9%, while the incidence of bladder neck sclerosis is 1.5% (17-20).

The published results of this procedure indicate its growing popularity. Compared to open prostatectomy, HoLEP is associated with significantly lower rates of hemorrhage and blood transfusions, with a shorter period of hospitalization and catheterization. Regarding symptomatology, as well as the occurrence and frequency of late complications, there is no difference between these two procedures. So far, the results of many randomized controlled studies comparing the results of TURP and HoLEP in the treatment of BPH have been published. In most studies, results related to the resection coefficient, symptom score, postmictive residual urine, and urine flow were better in the HoLEP group. A meta-analysis of these results shows that the HoLEP procedure is superior to TURP, in terms of perioperative hemorrhage, as well as periods of catheterization and hospitalization. In addition, the reduction in PSA values after the HoLEP procedure is up to 90%, while after TURP it is 71%. The main disadvantage compared to TURP is the longer learning curve for HoLEP (> 50 cases). Distant HoLEP results after 7 years of follow-up show durability in relation to the IPSS score, QoL score, as the maximum urine flow, resulting in the expressed satisfaction of the applied procedure in 92% of patients. Compared with TURP, there is no difference in the outcome of surgical treatment. Although initially described as an alternative to TURP, the HoLEP procedure has great potential to become a “volume-independent,” new gold standard in the surgical treatment of BPH (21-24).

The first holmium-laser enucleation of the prostate (HoLEP) in Serbia was performed in 2011, at the Urology Clinic of the Clinical Center of Niš. The first results of a comparative study in relation to TURP were published, with a follow-up period of one year. The results of this study show that, in relation to the period of catheterization and hospitalization, a decrease in hemoglobin levels, as well as a rate of early and late postoperative complications, the results are statistically significant and better in the HoLEP group. And, in relation to the results of postoperative monitoring related to QoL, IPSS and PVR, after 6 months and after 12 months from the operation, there is a statistically significant difference in favor of the HoLEP procedure. The operative time was statistically significant in duration during the HoLEP procedure, thus confirming the suggestions from the literature that a broader learning curve is inherent for complete mastery of this operative technique (27).

Holmium laser ablation (vaporization) of the prostate (HoLAP)

This method uses side-firing fibers (60° and 90°) and a 60W device. The results published in previous years show that it is a safe procedure that achieves effective deconstruction and improvement of urination quality (including IPSS and AUA symptom score), without significant perioperative morbidity and with a very low rate of re-operations after 7 years of follow-up. This procedure can also be used to treat larger volumes of prostate, with a lower rate and extent of hemorrhage and a shorter period of catheterization and hospitalization. The speed and efficiency of the procedure was limited by the low power of the device (60W), and the procedure itself was later overshadowed by the HoLRP and HoLEP procedures. Thanks to the appearance of a more powerful 100W device, as well as the growing popularity of the PVP KTP laser, interest in HoLAP has been renewed in recent years, and this procedure is recommended for small and medium-volume prostates (28-29).

Holmium laser resection of the prostate (HoLRP)

Holmium laser resection of the prostate is a procedure similar to transurethral resection, because the laser beam performs segmental resection of the adenoma all the way to the capsule. In relation to the volume of the prostate, the indication area is limited to 100 ml. Resection removes the tissue in small pieces, which are later exteriorized through the resectoscope sheath. The mass of the removed adenoma tissue is smaller in relation to the mass of the tissue removed by transurethral resection, due to the additional effect of HoLRP which vaporizes almost 50%. At the end of the operation, the appearance of the prostatic lodge is almost identical to the appearance it has after transurethral resection. Comparative studies in relation to TURP, after a follow-up period of 4 years, show lower perioperative morbidity, with similar results in relation to urodynamic parameters, IPSS, potency and continence (30,31).

CW2 Thulium laser

The CW2 thulium laser represents a new generation of lasers. With a wavelength of 2000nm, it provides better effects in continuous mode than in pulse mode. It can incise extraordinarily and has great hemostatic characteristics. Compared to the holmium laser, the thulium laser enables finer and more precise incisions It is also used for incisions of stenoses, tumors or renal parenchyma. The disadvantage in relation to the holmium laser is that the thulium laser is not used for lithotripsy. Surgical techniques in prostate surgery are similar to those of holmium lasers (HoLEP, HoLRP). Current studies show that the results of the holmium laser, when compared with the thulium laser, prostate enucleation are almost equal. Long term studies have not yet been conducted to confirm these preliminary results (31,32).

Conclusion

The evolution of lasers from coagulation to evaporation and enucleation of the prostate has provided urologists with a quality alternative for minimally invasive (operative) treatment of BPH, both in relation to transurethral resection of the prostate and in relation to open prostatectomy.

REFERENCES

1. Maiman TH. Stimulated optical radiation in ruby. Nature. 1960; 187: 493-4.
2. Einstein A. Zur Quantentheorie der Strahlung. Phys Z. 1917; 18: 121-8.

3. Teichmann HO, Herrmann TR, Bach T. Technical aspects of lasers in urology. World J Urol. 2007; 25: 221–5.
4. Bašić D. Fizičke osnove primene snažnih lasera u medicini. Magistarski rad; Medicinski fakultet u Nišu. Niš; 1997: 2-8.
5. Bašić D. Minimalno invazivno i hirurško lečenje benigne hiperplazije prostate. U: Prostata (Tomislav Pejčić, Jovan Hadži Đokić, Dragoslav Bašić, autori); Elit Medica, Beograd, 2014: 77-125 (ISBN 978-86-7222-104-8).
6. Bach T, Muschter R, Sroka R, Gravas S, Skolarikos A, Herrmann TR, Bayer T, Knoll T, Abbou CC, Janetschek G, Bachmann A, Rassweiler JJ. Laser treatment of benign prostatic obstruction: basics and physical differences. Eur Urol. 2012 Feb; 61(2): 317-25.
7. Grande M, Facchini F, Moretti M, Larosa M, Leone M, Ziglioli F, Pozzoli GL, Frattini A. Storia del Laser nella terapia dell'IPB [History of laser in BPH therapy]. Urologia. 2014 Jan-Mar; 81 Suppl 23: S38-42. Italian. doi: 10.5301/RU.2014.11985. Epub 2014 Mar 6. PMID: 24665033.
8. 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.
9. 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.
10. de la Rosette J, Collins E, Bachmann A, Choi B, Muir G, Reich O, Gomez-Sancha F , Tabatabaei S , Woo H. Historical Aspects of Laser Therapy for Benign Prostatic Hyperplasia. Eur Urol. 2012; 61: 317–325.
11. Dołowy Ł, Krajewski W, Dembowski J, Zdrojowy R, Kołodziej A. The role of lasers in modern urology. Cent European J Urol. 2015;68(2):175-82. doi: 10.5173/ceju.2015.537.
12. Kuntz RM. Current role of lasers in the treatment of benign prostatic hyperplasia (BPH). Eur Urol. 2006; 49: 961-969.
13. Te AE, Malloy TR, Stein BS, et al. Photoselective vaporization of the prostate for the treatment of benign prostatic hyperplasia: 12-month results from the first United States multicenter prospective trial. J Urol. 2004; 172: 1404–8.
14. 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.
15. Bachmann A, Schu¨ rch L, Ruszat R, et al. Photoselective vaporization (PVP) versus transurethral resection of the prostate (TURP): a prospective bi-centre study of perioperative morbidity and early functional outcome. Eur Urol. 2005; 48: 965–72.

16. Bouchier-Hayes DM, Anderson P, Van Appledorn S, Bugeja P, Costello AJ. KTP laser versus transurethral resection: early results of a randomized trial. J Endourol. 2006; 20: 580–5
17. Boxall NE, Georgiades F, Miah S, Dragos L, Armitage J, Aho TF. A call for HoLEP: AEEP for mega-prostates (≥ 200 cc). World J Urol. 2021 May 12. doi: 10.1007/s00345-021-03708-3. Epub ahead of print. PMID: 33978810.
18. Becker B, Gross AJ, Netsch C. Safety and efficacy using a low-powered holmium laser for enucleation of the prostate (HoLEP): 12-month results from a prospective low-power HoLEP series. World J Urol. 2018 Mar; 36(3): 441-447. doi: 10.1007/s00345-017-2159-5. Epub 2017 Dec 23. PMID: 29275506.
19. Netsch C, Becker B, Tiburtius C, Moritz C, Becci AV, Herrmann TRW, Gross AJ. A prospective, randomized trial comparing thulium vapoenucleation with holmium laser enucleation of the prostate for the treatment of symptomatic benign prostatic obstruction: perioperative safety and efficacy. World J Urol. 2017 Dec; 35(12): 1913-1921. doi: 10.1007/s00345-017-2071-z. Epub 2017 Jul 11. PMID: 28698991.
20. Becker B, Herrmann TRW, Gross AJ, Netsch C. Thulium vapoenucleation of the prostate versus holmium laser enucleation of the prostate for the treatment of large volume prostates: preliminary 6-month safety and efficacy results of a prospective randomized trial. World J Urol. 2018 Oct; 36(10): 1663-1671. doi: 10.1007/s00345-018-2321-8. Epub 2018 May 5. PMID: 29730838.
21. Enikeev D, Morozov A, Taratkin M, Misrai V, Rijo E, Podoinitsin A, Gabdullina S, Herrmann TRW. Systematic review of the endoscopic enucleation of the prostate learning curve. World J Urol. 2020 Sep 17. doi: 10.1007/s00345-020-03451-1. Epub ahead of print. PMID: 32940737.
22. Enikeev D, Glybochko P, Rapoport L, Gahan J, Gazimiev M, Spivak L, Enikeev M, Taratkin M. A Randomized Trial Comparing The Learning Curve of 3 Endoscopic Enucleation Techniques (HoLEP, ThuFLEP, and MEP) for BPH Using Mentoring Approach-Initial Results. Urology. 2018 Nov; 121: 51-57. doi: 10.1016/j.urology.2018.06.045. Epub 2018 Jul 24. PMID: 30053397.
23. Shigemura K, Fujisawa M. Current status of holmium laser enucleation of the prostate. Int J Urol. 2018 Mar; 25(3): 206-211. doi: 10.1111/iju.13507. Epub 2017 Dec 3. PMID: 29205507.
24. Kim A, Hak AJ, Choi WS, Paick SH, Kim HG, Park H. Comparison of long-term effect and complications between holmium laser enucleation and transurethral resection of prostate: Nations-wide health insurance study. Urology. 2021 Apr 29:S0090-4295(21)00349-6. doi: 10.1016/j.urology.2021.04.019. Epub ahead of print. PMID: 33933503.

25. Westenberg A, Gilling P, Kennett K, Frampton C, 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: 616-619.
26. Tan A, Liao C, Mo Z, Cao Y. Meta-analysis of holmium laser enucleation versus transurethral resection of the prostate for symptomatic prostatic obstruction. Br J Surg. 2007; 94: 1201-1208.
27. Basić D, Stanković J, Potić M, Ignjatović I, Stojković I. Holmium laser enucleation versus transurethral resection of the prostate: a comparison of clinical results. Acta Chir Iugosl. 2013; 60(1): 15-20.
28. Thurmond P, Bose S, Lerner LB. Holmium laser for the surgical treatment of benign prostatic hyperplasia. Can J Urol. 2016 Aug;23(4): 8356-62. PMID: 27544558.
29. Barski D, Richter M, Winter C, Arsov C, de Geeter P, Rabenalt R, Albers P. Holmium laser ablation of the prostate (HoLAP): intermediate-term results of 144 patients. World J Urol. 2013 Oct; 31(5): 1253-9. doi: 10.1007/s00345-012-0901-6. Epub 2012 Jul 11. PMID: 22782618.
30. Whiles BB, Martin AJ, Brevik A, Carrera RV, Thompson JA, Molina WR, Thurmon KL. Utilization of MOSES Modulated Pulse Mode Results in Improved Efficiency in Holmium:YAG Laser Ablation of the Prostate. Urology. 2021 Mar; 149: 187-192.
doi: 10.1016/j.urology.2020.12.024. Epub 2021 Jan 5. PMID: 33412223.
31. Tan A, Liao C, Mo Z, Cao Y. Meta-analysis of holmium laser enucleation versus transurethral resection of the prostate for symptomatic prostatic obstruction. Br J Surg. 2007; 94: 1201-1208.
32. Shao Q, Zhang FB, Shang DH, Tian Y. [Comparison of holmium and thulium laser in transurethral enucleation of the prostate]. Zhonghua Nan Ke Xue. 2009; 15: 346-349.