The Next Generation in Laser Treatments and the Role of the GreenLight High-Performance System Laser

Alexis E. Te, MD

Brady Prostate Center, Weill Cornell Medical College, Cornell University, New York, NY

Lasers have evolved over the past decade, with technical refinements that have resulted in a procedure that can achieve transurethral-like results in a safe and efficacious manner. The physics and characteristics of the laser light, such as wavelength and power densities, influence efficiency of treatment and safety profiles of various laser techniques and systems. The currently commercially available 80-W potassium-titanyl-phosphate laser used for photoselective vaporization of the prostate gland in men with lower urinary tract symptoms and benign prostatic hyperplasia has been shown to be a safe and effective therapeutic alternative for a wide spectrum of prostate sizes and configurations. Refinements based on clinical experience as well as progress in available technologies have produced an advanced system with improvements in beam quality and an increase in power to provide an increase in vaporization efficiency and flexibility in technique. The refinements require adjustments to current technique. The advanced technological developments enhance the utility of this laser for application in benign prostatic hyperplasia and urology.

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In the surgical treatment of symptomatic benign prostatic hyperplasia, lasers have slowly evolved from theory to practical application over the past few decades. More recently, advances in laser technology and growing clinical experience and overall utilization have produced refined techniques and devices, resulting in the efficient accomplishment of the surgical endpoints of benign prostatic hyperplasia (BPH) treatment.

For decades, the gold standard for BPH treatment was the transurethral resection of the prostate (TURP). However, complications and side effects of TURP, including fluid absorption, electrolyte imbalance, intraoperative and postoperative bleeding, and inadequate resection, have not made it a first-choice treatment, even among many less effective options. Having led the charge in other clinical applications, laser therapy promised several advantages over standard TURP, including technical simplicity and the absence or minimization of complications, such as intraoperative fluid absorption, bleeding, retrograde ejaculation, impotence, and incontinence. Laser therapy promised a shorter hospital stay and faster recovery. Hemostasis and limiting irrigant absorption—especially hypotonic, hyponatremic solutions—have allowed the treatment of larger prostate glands with laser prostatectomy and the treatment of patients with high surgical risk with less physiologic stress and less morbidity.[1,2] Not surprisingly, recent estimates demonstrate that an increasing number of practicing urologists are in fact already performing laser prostatectomies on patients with symptomatic BPH, and this number is increasing.

One laser that has gained widespread utilization during the last 5 years is the high-powered potassium-titanyl-phosphate (KTP) 532-nm wavelength photoselective vaporization laser system for the treatment of symptomatic BPH. This laser system is commercially marketed and manufactured as the GreenLight PV® photoselective laser vaporization system (American Medical Systems, Minnetonka, MN). The laser system is an example of a system suited to prostate surgery, and it has continued to improve with advances in technology and technique. We review the technical aspects affecting laser surgery and how these have influenced the development of next-generation advanced laser systems, such as the new 120-W high-powered 532-nm laser system, GreenLight HPS® (high-performance system).

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The Basics of Laser Surgery

The word "laser" is actually an acronym standing for "light amplification by stimulated emission of radiation." Laser light is characterized by being a single wavelength (monochromatic) of collimated coherent light that is emitted from an energized laser material (semiconductor, crystal, gas, or dye). This light carries energy that, when absorbed at a target chromophore, is converted to heat. The level of heat generated can be high enough to vaporize away the targeted material. In surgical applications, the laser energy can produce 2 laser tissue interactions: coagulation, the heating of tissue below the boiling/vaporization point but above the temperature threshold for protein denaturation; and vaporization, instant removal by heat above the vaporization/boiling point to evaporate away tissue.[3]

The rate of tissue ablation is determined by the rate of laser energy deposition into tissue, which in turn is also driven by the laser light wavelength (λ). In laser prostatectomy, one quickly delivers a sufficient amount of energy per unit volume of tissue to bring cells to vaporization temperature. If cells are brought only to coagulation temperature with lower power, then only coagulation occurs, desiccating surrounding tissue and interfering with the forward progress of vaporization/ablation. Additionally, the longer the application of laser light energy at lower power densities, the deeper the levels of coagulation. This can increase potential unrecognized periprostatic injury rather than creation of a channel defect. Thus, rate of power delivery is an important factor. The net amount of vaporization and coagulation effects produced by a laser can influence efficiency of tissue removal, persistence of unwanted side effects (eg, dysuria), and timing of the healing process. The relationship between temperature level and laser tissue effects is summarized in Table 1.[3]

Laser Wavelength Characteristics

A characteristic that distinguishes one laser from another is the specific absorption characteristic of specific

Table 1
Photothermal Conversion

Temperature Threshold (°C)	Biological Effect
37	Body temperature
45	Hyperthermia
60	Coagulation
100	Vaporization
150	Carbonization
300	Melting

The net mechanism of laser-induced tissue effect is the thermal conversion of laser energy, or photothermolysis. This process results in the elevation of target tissue temperature. These effects are categorized as either coagulation (ie, photopyrolysis) followed by delayed tissue sloughing, or vaporization (ie, photovaporolysis) resulting in immediate tissue ablation.

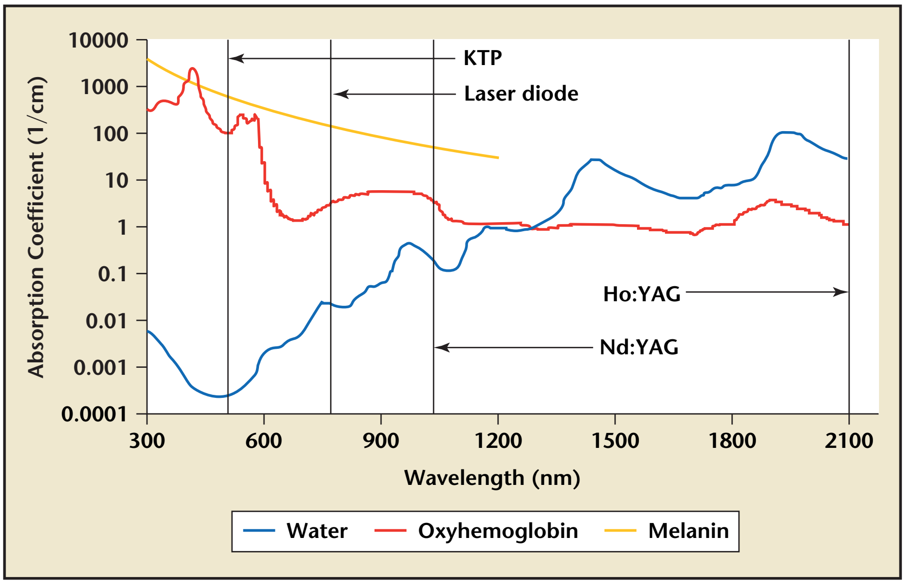

Figure 1. *Absorption characteristic for various wavelengths in 3 absorption media (water, oxyhemoglobin, and melanin). The absorption coefficient is plotted as a function of the wavelength, and the absorption coefficient for a given material is plotted on this graph. A high absorption coefficient means the given laser wavelength is well absorbed in the selected medium. A low absorption corresponds with a greater degree of transparency allowing the light to penetrate deeper into the medium. Note that the vertical scale is logarithmic; that is, each grid line is equivalent to a change of the absorption coefficient by 1 order of magnitude (factor 10). KTP, potassium-titanyl-phosphate; Ho:YAG, holmium yttrium aluminium garnet; nd:YAG, neodymium YAG.*

wavelength on various material and mediums, as well as depth of penetration in tissue. This is illustrated in Figure 1.

The KTP laser beam at a wavelength of 532 nm is fully transmitted through the aqueous irrigant but is highly absorbed by oxyhemoglobin in the tissue. This allows KTP laser energy to be selectively absorbed by tissue with high oxyhemoglobin content, such as prostatic tissue. This results in vaporization that is focused and more efficient in prostate tissue for vaporization; for this reason, the KTP laser procedure is referred to as photoselective vaporization of the prostate (PVP).

In contrast, the holmium yttrium-aluminum-garnet (Ho:YAG) laser energy is absorbed more by water, in the endoscopic irrigant, than by the tissue. Energy absorption by the irrigant forms a vapor bubble around the laser fiber tip. Tissue disruption/vaporization depends on the photomechanical heat interaction of this vapor bubble with the tissue. This interaction results in a microexplosion, causing a "jackhammer" effect that can tear tissue apart or break a stone. The Ho:YAG laser requires close contact to the target tissue and is, therefore, an ideal efficient laser scalpel for prostate procedures such as the holmium laser-assisted enucleation of the prostate, an alternative laser-based prostatectomy procedure.

Because 1064-nm neodymium YAG (Nd:YAG) and 830-nm diode lasers have similarly high absorption coefficients for water, oxyhemoglobin, and melanin, this translates into diffuse and nonselective absorption of laser light into tissue. This effect produces charring at the surface, resulting in black body effects and a deeper level of coagulation necrosis, which results in longer periods of postprocedure dysuria and retention. These characteristics have made Nd:YAG technology less popular and less widely used, despite increased vaporization efficiency with higher powers.

Certain laser wavelengths also penetrate tissues differently. Laser energy that is not reflected or scattered off the surface of tissue subsequently penetrates the tissue. The penetration depth depends on wavelength, absorption coefficient, and composition of the receiving tissue. Penetration is often described by "extinction length," the depth of penetration of an incident beam beyond which only 10% of the initial beam energy is left (ie, 90% absorption). With its longer extinction length, 1064-nm Nd:YAG energy penetrates tissue twice as deep as the 830-nm diode laser, and 10 times more than the 532-nm KTP laser. This effect can diffuse power delivered and allow coagulation necrosis to predominate, unlike the shorter extinction lengths of 532-nm and 2100-nm holmium. This is illustrated in Figure 2.

Thus, in laser vaporization prostatectomy, efficient delivery of light energy to produce a concentrated vaporization effect with limited

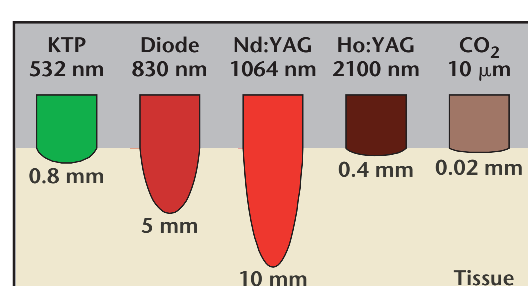

Figure 2. *Optical penetration depth of each particular wavelength into tissue. KTP, potassium-titanyl-phosphate; Ho:YAG, holmium yttrium aluminium garnet; nd:YAG, neodymium YAG.*

coagulation necrosis is the desired effect. A wavelength with power that can penetrate tissue with the effectiveness to result in predominant vaporization with limited coagulation necrosis is desired. As such, the 532-nm wavelength laser system, with its transparency in an aqueous medium, is an ideal transurethral laser to vaporize tissue efficiently with limited coagulation necrosis.[3]

Potassium-Titanyl-Phosphate Laser

Photoselective Vaporization of the Prostate

Doubling the frequency of pulsed Nd:YAG laser energy with a KTP crystal led to the creation of a 532-nm wavelength laser with substantially different tissue interaction properties compared with its parent Nd:YAG. As discussed, the KTP wavelength is selectively absorbed by hemoglobin, which acts as an intracellular chromophore. KTP laser energy is transparently delivered through a fluid medium, such as water, into the cell, where it is absorbed by hemoglobin and rapidly heated, leading to rapid vaporization of tissue. The wavelength's short optical penetration confines high power laser energy to a superficial layer of prostatic tissue that is vaporized rapidly and hemostatically with only a 1- to 2-mm rim of coagulation with the optimal technique.[4]

PVP is currently performed with an 80-W KTP side-firing laser system (GreenLight PV) through a 23-F continuous-flow cystoscope with normal saline as the irrigant. The ADDStat side-firing laser fiber (Laserscope) has special markings on the tip to facilitate its safe use. The procedure can be performed with a range of anesthesia from a local prostate block with intravenous sedation to regional anesthetic to general anesthesia. Often, no postoperative irrigation is required, and catheter time is relatively short.[4]

A prospective multicenter study by 6 US institutions has reported favorable and durable efficacy up to 3 years with a low retreatment rate and low side effect profile.[5,6] Because of its hemostatic advantages, it has been used in high-risk patients (eg, those undergoing anticoagulation with heparin, warfarin, nonsteroidal anti-inflammatory drugs, and aspirin) with excellent safety and efficacy outcomes. One finding demonstrated in this study was that up to 3-year durability in efficacy was attained, despite the treatment cohort representing the centers' initial experience with the technology. Average operative time of 38.7 minutes for an average prostate volume of 54.6 mL seemed to be comparable to that with TURP.[5,6]

However, a challenging application is treatment of large prostate glands. For example, although PVP was shown to be safe and effective in the first reported series of 64 men with symptomatic benign prostatic hyperplasia and large-volume prostate glands (mean preoperative volume 101 cm^3), the procedure was long (average laser time 121 minutes).[7] As a result, modification from a pure vaporization technique led to a vaporization incision technique that resulted in a mild decrease in operative time. The main rate-limiting factor was the amount of efficient vaporization that could occur per unit of time.[8]

Over the past 5 years, experience with the current 532-nm wavelength KTP-based GreenLight system among both novice and experienced surgeons on an expanding base of patient populations and prostate sizes has led to technical refinements to the current system to increase vaporization efficiency. These refinements were intended to decrease operative time in a variety of surgical techniques and to provide a more consistent vaporization effect on a wider variety of prostate compositions.

Current PVP Technique With GreenLight PV

The current technique of PVP with the GreenLight PV system as described by Malek and colleagues uses a side-to-side sweeping technique with the side-fire fiber moving from the area of the bladder neck to approximately the level of the veru in a clockwise–counterclockwise fashion to create an open TUR-like cavity.[9] An important sign of vaporization efficiency is bubble formation, which signifies vaporization of tissue. Without bubbles occurring with tissue removal, the predominant effect is coagulation necrosis. To maintain maximum delivery of light energy to target tissue, a 0.5-mm distance or less (near contact) is recommended to effect maximum vaporization efficiency. If the distance was greater, less efficient lower light power density was being delivered, with a consequent potential increase in coagulation necrosis. With this laser system and technique, the vaporization of a large prostate gland was tedious and required a long lasering time because of the limited rate of power per unit of time.[4]

To increase vaporization efficiency, technical refinements focusing on beam characteristics and quality resulted in a higher-power 532-nm wavelength laser system, GreenLight HPS.

Advanced PVP With the GreenLight HPS Laser

To increase vaporization efficiency, technical refinements focusing on beam characteristics and quality resulted in the evolution of a new higher-power 532-nm wavelength laser system, GreenLight HPS (Figure 3). This advanced laser system delivers the same 532-nm wavelength with the same inherent absorption characteristics, but with laser diodes instead of an arc lamp as the energy source to energize an Nd:YAG laser rod, the output of which is then frequency-doubled to the 532-nm wavelength. This allowed the system to deliver up to 120 W of quasi-continuous power for potentially higher vaporization efficiency. System modifications added a dual-power mode feature with 2 pedals: 1 for vaporization effect at high powers, and 1 for coagulation effect at lower powers. The advanced system also uses an improved fiber with a highly reflective coating that limits the back-scatter effect, which resulted in the unwanted lasering of nontargeted tissue.[1] These changes in beam characteristics, fiber differences, and higher power range are significant enough not only to effect higher rates of tissue removal but also to produce changes in techniques and training that are different from those with the GreenLight PV system. With this higher power and change in beam characteristics, awareness and precaution need to be exercised. The modifications of the advance system have changed power settings used in specific situations, fiber life, tissue distance for vaporization, speed of procedure, coagulation technique, treatment of fibrous glands, and technique when approaching the surgical capsule.

Figure 3. *The New GreenLight HPS® laser system.*

Advancements in Beam Quality and Power With GreenLight HPS

The first important modification is the beam quality and characteristic. The standard GreenLight PV beam has a maximum focus and power density at 0.5 mm from the fiber. At a greater distance divergence occurs, with a consequent decrease in power density. The new GreenLight HPS has a beam quality that maintains focus with negligible divergence up to 3 mm from the fiber and with limited divergence at 5 mm. This means that power density is maintained up to 3 mm from the fiber and up to 5 mm, with minimal change in power density. This means that effective vaporization can be maintained with increased distance from the target tissue (up to 3–5 mm), which allows vaporization to be consistently efficient despite variable changes in distance within 3 mm to 5 mm from the fiber. These modifications are diagrammed in Figure 4.[10]

The second and significant advancement is the increased power range of up to 120 W that can be delivered by the new system. This is a 50% increase in power over the standard GreenLight PV and results in increased vaporization efficiency. However, with greater power comes greater surgical responsibility to be accurate and selective, because this system can more quickly create a surgical defect and penetrate structures that were previously more difficult to vaporize, such as fibrous tissue.

Essential Modification and Precautions of Surgical Technique With GreenLight HPS

The increase in beam quality, resulting in a tighter and more consistent beam profile over a greater distance, allows the surgeon to work at a greater distance from tissue without a loss of vaporization efficiency. A true non-contact technique should be used and maintained. To maintain the quality of the fiber and limit degradation secondary to reflective heat, good irrigation and distance from tissue need to be maintained, especially at higher powers. Unlike the standard GreenLight PV, with which laser application at a distance of 1 mm to

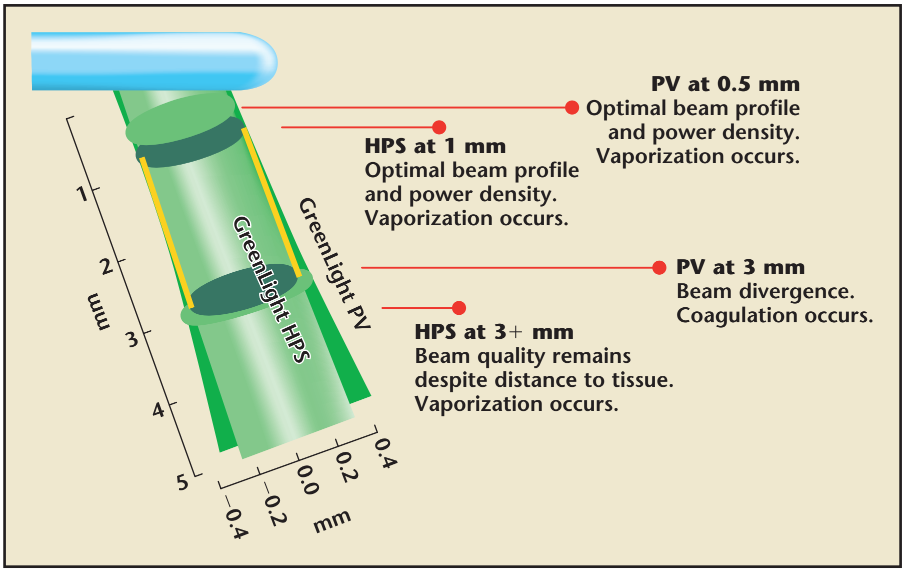

Figure 4. *Comparison of GreenLight PV® and GreenLight HPS® beam characteristics.*

3 mm may increase coagulation necrosis, vaporization efficiency is maintained with GreenLight HPS. The main caveat with this tighter beam profile, especially at higher powers, is the potential to inadvertently laser deeply into the bladder wall when the fiber is pushed into passed bladder neck, resulting in potential perforation or injury to the ureteral orifice. Additionally, stationary laser application at high powers should be avoided because of the potential to create a deep unwanted defect quickly in the treated area. A sweeping technique with good irrigation is usually the preferred technique.

The ability to utilize a range of vaporization power from 60 W to 120 W allows more flexibility in a number of clinical situations with excellent results. The main goal of higher power with tighter beam profile is to vaporize and remove tissue with less lasing time, allow more efficient removal of fibrous glands, and treat larger glands in less time. At high powers, the visualization of a flurry of bubbles demonstrates its increased vaporization efficiency. However, precautions must be taken with higher power because increased vaporization efficiency can result in less hemostasis and increased fiber degradation from the increased heat produced. As such, certain clinical guidelines and power settings are recommended as starting points and during treatment in certain situations.

In general, the lowest vaporization setting that produces the desired vaporization effectiveness for creating surgical result is the goal. In all glands, the initial starting power is 60 W to 80 W before increase in power. In general, the 80-W power setting is sufficient in most applications to vaporize the prostate effectively. However, when there is a desire to increase vaporization efficiency by increasing power in a clinical situation such as a fibrous or very large prostate gland, it is essential that excellent irrigation is present to flow over the fiber and treatment areas. It is also important to maintain sufficient space in the treatment area to provide a non-contact technique with the higher power. These technical considerations are necessary to prevent unwanted premature fiber degradation due to higher heat produced by the combination of higher power and tighter beam profile. With this high power, high vaporization technique, especially at 120 W, large hot vapor bubbles are produced, and contact with the fiber should be avoided with proper distance and good irrigation to prevent fiber degradation. At higher power, it is also important to keep the fiber clean of adherent tissues because these tissues can act as a heat sink to degrade the fiber. High power at 100 W to 120 W should be cautiously applied and lowered when possible to prevent capsular perforation when approaching the surgical endpoint near the capsule.

An advantageous feature of GreenLight HPS is the dual-mode power pedal feature that allows instant selection of a lower power setting for coagulation without vaporization. This feature allows the surgeon to quickly address bleeding areas with close low-power application to attain hemostasis. The general setting is usually 20 W to 30 W in a sweeping near-contact or contact technique.

The Role of GreenLight HPS in the Surgical Treatment of BPH

The GreenLight HPS system is designed to provide flexibility for the experienced laser surgeon in a number of applications, owing to the larger selection of treatment parameters offered. The important variables controlled by the surgeon are power selection (60–120 W for vaporization, 20–40 W for coagulation), working distance between fiber and tissue, irrigation flow, and sweeping speed.

In small (< 40 cm^3) and medium (40–70 cm^3) prostate glands, a starting point of 60 W and an increase to 80 W should be sufficient, except for the occasional fibrous prostate gland. With larger prostate glands (> 70 cm^3), power may be cautiously increased, with the caveat that the surgeon is able to attain a good working distance from the target tissue with good irrigation flow through the scope to keep the fiber cool. Of note, cooling of tissue by irrigation also limits coagulation necrosis secondary to heat transductive effects from the point of vaporization. A proper sweeping technique also limits this transductive heat effect, limiting the depth of coagulation necrosis by not staying at any one point too long. A power setting of 100 W to 120 W should be selected only to vaporize large areas quickly. Power should be lowered to 80 W as one approaches the capsule or when a high power setting is not needed. With large intravesical prostate glands, caution should be exercised when applying the laser in intravesical positions, and accuracy is important. A setting of 60 W to 80 W is advised to maintain control and limit inadvertent treatment of bladder wall. The vaporization incision technique is especially useful with large intravesical components but is only recommended for the experienced laser surgeon.

In high-risk patients undergoing anticoagulation therapy and in high surgical risk patients, the 60 W to 80 W setting is preferred to effectively provide the optimum combination of hemostasis and vaporization efficiency.

Finally, the role of GreenLight HPS in other urological applications may be considered with the increased flexibility of a wider range of power settings. Applications of GreenLight PV such as in the treatment of bladder tumors as well as urethral strictures can be considered (see the article by Dr. Kaplan in this issue).[11] Generally, lower power settings are required with urethral strictures, and a low coagulation setting is usually the preferred setting for the highly vascular and laser-sensitive bladder tumors, to avoid perforation of the bladder wall.

Conclusion and Summary

Laser prostatectomy has evolved as an advantageous technique for the efficient removal of prostate tissue for the treatment of symptomatic BPH, with an excellent safety profile. The high-power 532-nm wavelength laser can hemostatically vaporize prostate tissue in an efficient photoselective manner, as demonstrated by many studies. Technological advances based on clinical experience with the GreenLight PV laser led to the development of a higher-power laser with an improved beam profile, GreenLight HPS. This higher-power laser can efficiently remove prostate tissue in less time and provide flexibility to treat a broader range of prostate glands effectively and efficiently. However, with greater power and flexibility comes greater responsibility for the surgeon to select the appropriate parameters to safely vaporize target tissue. With appropriate training of surgeons, GreenLight HPS broadens the range of prostate gland types that can be treated safely in a fast, efficient, and effective manner. ■

References

1. Santarosa RP, Te AE, Kaplan SA. Transurethral resection, incision and ablation of the prostate. In: Graham SD, ed. *Glenn's Urologic Surgery*, 5th ed. Philadelphia: Lippincott, Williams and Wilkins; 1998:921-931.
2. Te AE. The development of laser prostatectomy. *BJU Int.* 2004;93:262-265.
3. González RR, Lee R, Sandhu J, Te AE. Laser prostatectomy. In: Scardino PT, ed. *Atlas of the Prostate*, 3rd ed. Philadelphia: Current Medicine; 2006.
4. Lee R, Gonzalez RR, Te AE. The evolution of photoselective vaporization prostatectomy (PVP): advancing the surgical treatment of benign prostatic hyperplasia. *World J Urol.* 2006; 24:405-409.
5. 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;172:1404-1408.
6. Te AE, Malloy TR, Stein BS, et al. Impact of prostate-specific antigen level and prostate volume as predictors of efficacy in photoselective vaporization prostatectomy: analysis and results of an ongoing prospective multicentre study at 3 years. *BJU Int.* 2006;97:1229-1233.
7. Sandhu JS, Ng C, Vanderbrink BA, et al. High-power potassium-titanyl-phosphate photoselective laser vaporization of prostate for treatment of benign prostatic hyperplasia in men with large prostates. *Urology.* 2004;64:1155-1159.
8. Sandhu JS, Te AE. Photoselective vaporization of the prostate—the vaporization incision technique for large volume prostates. AUA online video library. 2005 AUA video session (DVD code 05DVDSES6). *J Urol.* 2005;173:366.
9. Malek RS, Kuntzman RS, Barrett, DM. High power potassium-titanyl-phosphate laser vaporization prostatectomy. *J Urol.* 2000;163:1730-1733.
10. Laserscope. *Greenlight HPS Product User Manual, Specifications Sheet, and Training Manual.* San Jose, CA: Laserscope; 2006.
11. Kaplan SA. Expanding the role of photoselective vaporization of the prostate. *Rev Urol.* 2006; 8(suppl 3):S3-S8.

Main Points

- Advances in laser technology and growing clinical experience have produced refined techniques and devices, resulting in the efficient accomplishment of the surgical endpoints of benign prostatic hyperplasia (BPH) treatment.
- The high-powered potassium-titanyl-phosphate 532-nm wavelength photoselective vaporization laser system is being used safely and effectively in the treatment of symptomatic BPH.
- The potassium-titanyl-phosphate laser beam at a wavelength of 532 nm is fully transmitted through aqueous irrigant and highly and selectively absorbed by oxyhemoglobin, such as that in prostatic tissue.
- The GreenLight HPS laser can efficiently remove prostate tissue in less time and provides flexibility to treat a broader range of prostate glands effectively and efficiently.