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UROLOGIC LASER TYPES AND INSTRUMENTATION

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Summary.- *Though the primary role of lasers in urology has always been in the treatment of urolithiasis, there are several other indications for their use. There are many different types of lasers currently available, each with unique properties conducive to treating certain disorders. As such, it is critical that today's urologist understands each laser's characteristics in order to optimize patient selection and treatment. The lasers which are primarily used in urologic applications include the carbon dioxide (CO_2) laser; the Neodymium:Yttrium-Aluminum-Garnet (Nd:YAG); the Potassium Titanyl Phosphate (KTP) laser and the Holmium:YAG (Ho:YAG) laser. This review focuses on the unique characteristics of each of these lasers as well as the instrumentation needed utilize and deploy these tools in the urinary tract.*

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Resumen.- *Aunque el uso primario de láser en urología ha sido siempre el tratamiento de la litiasis, hay otras indicaciones para su utilización. Existen muchos tipos diferentes de láseres actualmente disponibles, cada uno de ellos con unas propiedades únicas que les permiten tratar ciertas enfermedades. Es crítico que el urólogo actual entienda las características de cada láser para optimizar la selección del paciente y el tratamiento. Los láseres utilizados primariamente en aplicaciones urológicas incluyen el láser de dióxido de carbono (CO_2); el de Neodinio:Ytrio-Aluminio-granate (Nd:YAG); el láser de potasio titanilo y fosfato (KTP), y el de Holmio:YAG (Ho:YAG). Esta revisión está enfocada a las características únicas de cada uno de estos láseres, así como al instrumental necesario para utilizarlos en el aparato urinario.*

Palabras clave: *Endourología. Instrumentación. Fibra. Láser.*

INTRODUCCIÓN

In 1905 Einstein wrote a Nobel prize winning paper describing the photoelectric effect (1). One of the many premises set forth in this paper was the existence of the photon. The identification of this particle, which possesses wave-particle duality, was critical in the identification and generation of laser energy.

The acronym laser, which stands for Light Amplification by the Stimulated Emission of Radiation, was coined by Gould in 1957. There are three properties which give laser light its unique properties and differentiate it from natural and incandescent light. Unlike natural light, which is created by spontaneous emission, laser light is produced by controlled, stimulated emission. This produces light with completely in-phase photons. This characteristic is called *coherence*. The second property of laser light, is that it has a high degree of *collimation*. The mirrors within a laser are designed to emit photons which only travel in one direction; this explains why laser light does not disperse like regular light, and why the light emitted by a laser pointer is nearly the same diameter at the source and the target. The third property of laser light is its *monochromaticity*. Because the stimulated emission of light is produced by multiple identical electron transitions, all photons produced are of the same wavelength.

The first working laser was created and demonstrated in 1960 by Theodore Maiman (2). Since then, several different types of lasers have become commercially available, many of which have utility in medicine. Distinctions between the various laser systems are based on the wavelength of light produced, the resultant power supplied and the mode of energy emission (pulsed or continuous) (3). These characteristics determine the absorption and depth of penetration in tissue (4).

The first description of lasers being utilized in urologic surgery was published by Parsons in 1966 (5). Since then, lasers have been utilized for benign and malignant conditions affecting the kidney, ureter, bladder and prostate. There are several different types of lasers currently available, each with unique properties conducive to treating certain disorders. As such, it is critical that today's urologist understands each laser's characteristics in order to optimize patient selection and treatment (6).

Laser-Tissue Physiology

Although lasers are used to treat a number of urologic conditions (7), their primary role in urology has always been in the treatment of urolithiasis. More recently, BPH has become a common application (8). Lasers can create three different reactions when they are utilized on tissue (9, 10). The first is a *photothermal* effect. Upon contact with tissue, laser energy is transformed into heat, causing protein denaturation, coagulation, carbonization and, ultimately, vaporization, if enough energy is dispended (4). A *photomechanical* reaction results in the forced expansion and collapse of a bubble just after application of pulsed laser energy. This reaction creates hydrodynamic pressure which can then be used to force drugs into or through certain tissues (11). Lasers can also be used to convert an inert drug into a toxic one, producing local effect. This is a *photochemical* reaction (12). Another novel use for lasers is for tissue-welding. Lasers have been used to reapproximate tissues in order to reconstruct anatomical structures (13). This new effect has been tested for urethral reconstruction, pyeloplasty, urinary diversion and laparoscopic surgery (14-18).

CO_2 laser

The carbon dioxide (CO_2) laser is one of the first lasers used medically. This laser's ability to cut and produce hemostasis was noted by Yahr and Strully in 1966 (19). The CO_2 laser produces radiation at a wavelength of 10600nm. It is absorbed by water and can produce hemostasis in blood vessels up to 0.5mm in diameter (20). The CO_2 laser can be delivered through two different systems. The first emits energy through an optical system which incorporates a microscope. The second delivers energy via an internal mirror and an articulated surgical arm (21). The CO_2 laser produces surface vaporization with less than 0.1 mm of tissue penetration (22). Its primary urologic applications are for superficial skin lesions (23), and it is currently the treatment of choice for extensive or recurrent genital condyloma acuminata (24). This laser's use, however, has been limited by the lack of an effective endoscopic delivery system, thereby limiting its use for intracorporeal and intraurethral lesions. There is currently work underway to develop such systems (25).

Nd:YAG laser

The Neodymium: Yttrium-Aluminum-Garnet (Nd: YAG) laser produces energy at a wavelength of 1.064 nm (26). The 20-30W energy created by this laser produces effective coagulation and deep tissue ablation, with a penetration depth of 5-6mm (27). The Nd:YAG was the first laser used to treat transitional cell carcinoma (TCC), and while it is still in limited use for this application, it has largely been replaced by the holmium:YAG laser (28, 29). In a series of 60 patients, Schmiedt and coworkers reported 5% decrease in local bladder recurrence when treating superficial tumors with the Nd:YAG laser (30). The depth of penetration and hemostatic properties of this laser have made it a good option in the treatment of superficial penile carcinoma (31) and bladder hemangioma (32). Although the Nd:YAG laser can be used for laser lithotripsy, the holmium laser is more effective and has less associated morbidity (27).

The energy efficiency of the Nd:YAG laser is low, with 90% of energy utilization generating wasted heat. Because of this, the Nd:YAG generator requires a high power electric outlet and special electric installation (3). Additionally, the Nd:YAG requires a silica laser fiber for energy delivery. Direct contact between this fiber and the tissue must be avoided to prevent tissue charring which can reduce the laser's ablative efficiency (7).

KTP laser

The Potassium Titanyl Phosphate (KTP) laser is a direct descendent of the Nd:YAG laser. The major modification between the two was the introduction of a KTP crystal on the laser resonator which allows the generator to produce energy at a wavelength of 532nm. Like the Nd:YAG laser, the KTP laser also requires special electrical outlets and, in most cases, an external water cooling system (3).

What makes the KTP laser unique is this laser's strong avidity for hemoglobin, resulting in highly efficient hemostasis. Its depth of tissue penetration is 0.8mm (4); however it only penetrates a few microns into vascular tissues. Additionally, it is completely transmitted through saline, obviating the need for glycine irrigation.

Due to its wavelength and quasi-continuous wave operation mode, the KTP laser has been primarily used for soft tissues. In urology, the KTP laser, which is marketed under the name GreenLight™ laser, has been rapidly adopted to treat benign prostatic hypertrophy (BPH) (10). This procedure, known as photovaporization of the prostate (PVP), is as effective as standard transurethral resection (TUR) procedures, but because of its immediate coagulative effects on hemoglobin, it offers superior hemostasis and vision without the risk of TUR syndrome associated with glycine irrigants. Additionally the actual technique is somewhat similar to a standard TURP, making it easy to learn to use (33).

Ho:YAG laser

The newest and most widely utilized laser for urologic applications is the Holmium:YAG (Ho:YAG) laser. The Ho:YAG laser is delivered through low OH silica fibers, ranging in diameter from 150 to 940 microns (33). The Ho:YAG laser has become the gold standard for most procedures in endourology today, in part due to the availability of flexible fibers of different calibers which can easily be passed through flexible endoscopes.

The Holmium:YAG laser produces energy at a wavelength of 2100nm with a pulse duration of 350 milliseconds. Because of these properties, the Ho:YAG laser's energy is promptly absorbed by water and water containing tissues, resulting in rapid dispersion of heat (7). Unlike the Nd:YAG laser, the Ho:YAG laser requires contact with target tissue. When used with irrigation systems, the Ho:YAG laser penetrates tissue only 0.4mm and produces thermal damage in the contiguous 0.5-1mm (29). Because of its shallow depth of penetration, the Ho:YAG laser allows tissue to be gradually incised or coagulated, with higher precision than the Nd:YAG laser (7).

An additional benefit of the Ho:YAG laser is better visualization at the point of contact. Typically, at the onset of energy application, steam bubbles are generated at the tip of the laser fiber, obscuring vision in that area. The bubbles produced by the Ho:YAG laser, however are much smaller and have a lifetime of only 500 milliseconds, creating minimal impact upon endoscopic vision (34).

A number of applications for Ho:YAG laser have been reported in the literature, including stone disease (35), BPH (36), ureteral strictures (37), ureteropelvic junction (UPJ) anomalies (38), and malignancy (35). Currently it is most widely utilized for treating nephrolithiasis.

INSTRUMENTATION

Endoscopic instrumentation

The accurate, effective and safe delivery of laser energy is more often limited by the endoscopic tools used to deliver the energy rather than the laser itself. Because the mechanical properties of laser energy delivery inherently limit the pliability and size of available fibers, endoscopes which ameliorate these limitations are in large demand.

Lasers are most commonly utilized with flexible and semi-rigid ureteroscopes, as well as cystoscopes. The choice of the right device will largely depend on the location of the pathology. Bladder and prostate conditions are most frequently treated with rigid cystoscopes, though laser energy can safely be delivered through flexible cystoscopes. Antegrade upper tract procedures utilize even larger nephroscopes. These endoscopes can accommodate large ultrasonic devices which can treat extensive stone disease more quickly than lasers; however for nephron-sparing treatment of upper tract TCC, holmium laser energy is a mainstay of treatment. Both cystoscopes and nephroscopes have large lumens which easily accommodate 500 and 1000 micron fibers.

Semi-rigid ureteroscopes are often preferred for distal ureteral lesions, as they provide better vision and control than their flexible counterparts. Flexible ureteroscopes, however, are required for the retrograde treatment of proximal ureteral and renal collecting system conditions. These endoscopes, which are easily damaged by laser energy, have an increasingly limited degree of deflection as larger laser fibers are used, making already difficult lower pole pathologies, more complicated to access. Additionally the small working channels of these instruments is largely occluded by even the smallest laser fibers, limiting irrigant flow and vision (39).

Several adaptations to endoscopes have been introduced to ameliorate the effect of laser fibers on scope function. The DUR-8 Elite (Gyrus ACMI, Southborough MA) was the first ureteroscope to introduce an active second point of deflection which allows for additional downward deflection while the Flex-X ureteroscope (Karl Storz, Culver City CA) has incorporated increasingly acute angles of deflection. Dilating and non-dilating ureteral access sheaths allow larger caliber ureteroscopes to be introduced easily into the upper tract as well.

Laser Fibers

Laser fibers are required to deliver laser energy to the target point. To fit through endoscopes, the fibers must be thin and flexible; however the inherent properties of laser energy require that laser fibers maintain a certain degree of rigidity in order to transmit energy to the target. Laser fibers are generally composed of an inner circular core, usually made from silica, for energy transmission, and two or three outer layers which confine laser radiation and providing mechanical stability (3). Failure to confine energy emission to the tip of the laser can result in damage to equipment and injury to personnel (40). Silica fibers are relatively inexpensive while still being biocompatible, flexible, and capable of repeatedly transmitting high energy. Thinner fibers are, in general, more flexible and provide higher laser intensity at the distal tip (3), although this makes the tip more delicate and prone to breakage (10). Laser fiber tips can be adapted to allow end-firing, side-firing or radially dispersion. The use of a side-firing fiber is particularly valuable in the prostate, while end-firing is most frequently utilized for stone disease. For renal parenchymal diseases, the use of a radial diffuser tip creates circumferential interstitial laser ablation, resulting in cell death and hemostasis (41). Newer hollow laser fibers, though not currently in wide use, are also available. These glass or polycarbonate fibers are capable of delivering directional high-power laser energy useful for sealing tissues (41-44).

The development of laser fibers of multiple diameters has been critical to the success of the Ho:YAG laser. Application of the correct fiber size optimizes surgical performance. Table I shows currently available fiber sizes and their appropriate applications. Additionally, as medical cost containment continues to be critical issue, it must be noted that there is a substantial difference in the price of different sized laser fibers: in general, the 365 micron laser fibers are substantially less expensive than the small (270 micron) or large (1000 micron) fibers.

Irrigants

All lasers utilized in urologic surgery convert part of their initial energy input into heat. Because of this, an aqueous irrigant is required to disperse heat, protect surrounding tissues, and distend the work-space. As stated previously, because lasers are fully transmitted by irrigants, the need for special solutions such as glycine is abrogated. Irrigants may be delivered by gravity drainage, pressurized flow, manual pressure or infusion device. Infusion devices, such as the Peditrol (Peditrol, Durban, South Africa) is a hands-free, foot pedal controlled device that delivers a bolus of irrigant through the ureteroscope. Honey and colleagues found that the Peditrol was able to deliver higher irrigant flow and was superior to other irrigant delivery methods use during laser treatments (45).

Adjuvant Devices

Despite the symbiotic functional relationship between endoscopes and lasers, lasers are often endoscopes' worst enemy. Firing the laser too close to, or inside of, the endoscope tip results in expensive endoscope repairs while the laser fiber itself can damage the working channel of flexible ureteroscopes. Until recently only good laser use technique could be used to prevent these complications.

The FlexGuard laser sheath (LISA Laser Products, Katlenburg-Lindau Germany) was designed to protect the working channel from damage caused during insertion of the laser fiber. In laboratory studies, the FlexGuard laser sheath significant decreased the amount of force required to insert the laser fiber in the the endoscope, but it also decreased the scope's angle of deflection and maximal irrigant flow (46). Additionally the sheath was not designed to protect endoscopes from what is perhaps a more imminent threat: laser energy damage.

The endoscope protection system (EPS) (Gyrus ACMI, Southborough MA), on the other hand, is a novel system designed to protect endoscopes from laser energy damage. The EPS is not a separate piece of equipment; rather it is an automatic shut-off mechanism which is incorporated directly into the laser generator when the blue cladding of the laser is not detected in the field of vision. Though not commercially available at the current time, the system has, in preclinical testing, proven to be highly effective (Figure 1) (47).

Another problem which commonly occurs during laser lithotripsy is migration of stone fragments to other parts of the urinary system. Though the use of lower pulse repetition rates can reduce rates of stone migration, stone migration still occurs in 40% to 50% of proximal ureteral stones cases and 5% to 10% of distal ureteral stone cases (48). This stone migration increases operative time, cost, and morbidity. Surgeons have traditionally used a number of maneuvers, including reverse Trendelenberg position to optimize the effects of gravity and decreased irrigation pressure. Both of these techniques, however, compromise surgeon comfort and visibility and can therefore also prolong procedures. Ali and colleagues suggested an alternative method, using lubricating jelly instilled proximal to the stone before applying the kinetic energy (49). More recently several endoscopic devices have been developed to prevent stone migration. For endoscopic procedures, the Lithocatch®, Parachute®, 12 Fr balloon catheter (4,5), Dretler Stone Cone (48, 50-53) (all produced by Boston Scientific Corp., Boston, MA), PercSys Accordion® (Percutaneous Systems Inc., Mountain View, CA) and NTrap® Basket (Cook Medical, Bloomington, IN), and a variety of thermosensitive polymers (54) have all been utilized. These

TABLE I. HO:YAG LASER FIBER SELECTION BY APPLICATION.

Application	Laser Fiber
Bladder stones or tumors	1000µ
Distal and Mid-ureteral stones or tumors	200µ, 365µ
Proximal Ureteral stones or tumors	200µ
Renal stones or tumors (Retrograde approach)	200µ
Renal stones or tumors (Antegrade approach)	200, 365 or 1000µ
Prostate ablation	1000µ

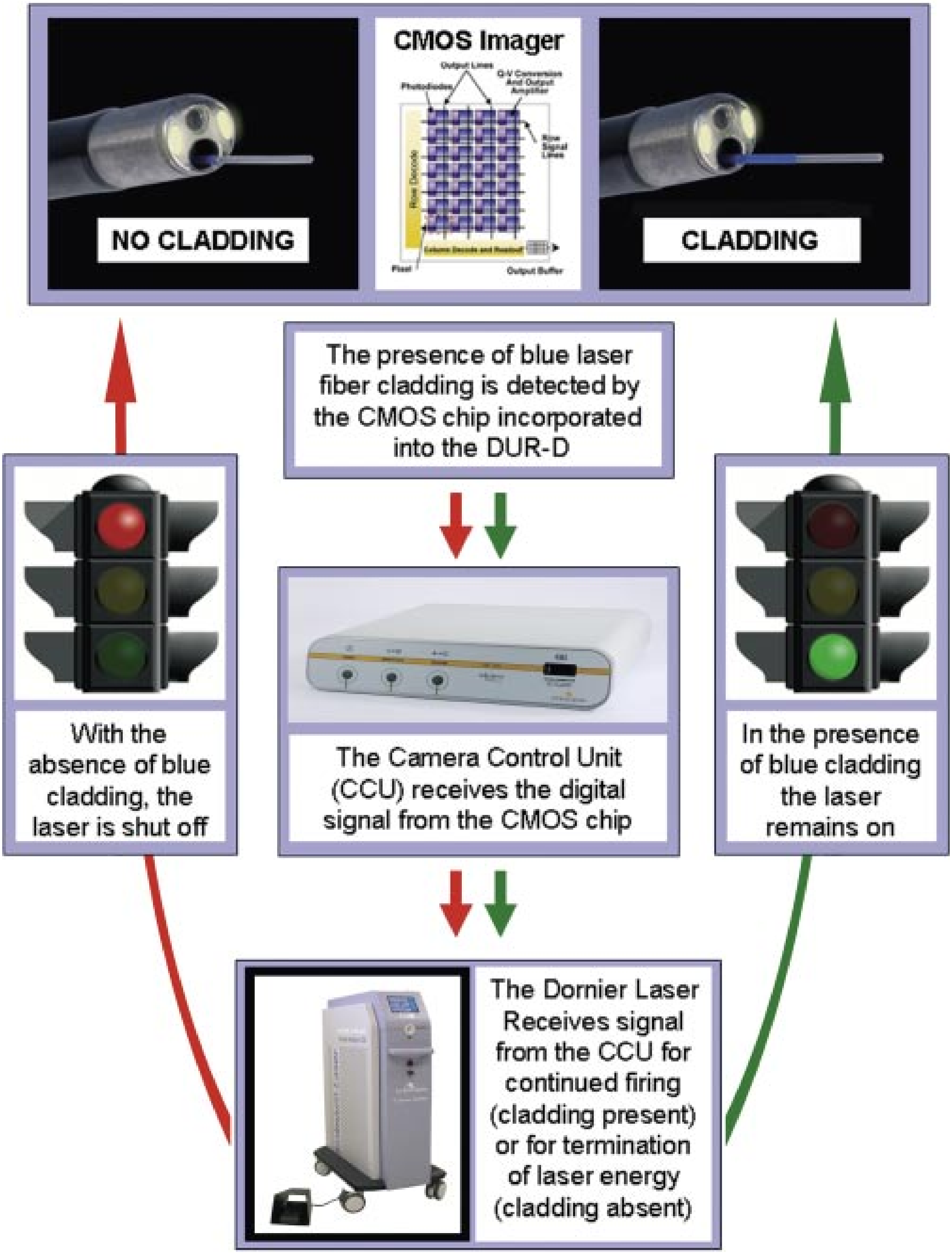

FIGURE 1. Schematic representation of the Endoscope Protection System.

devices have allowed surgeons to use of higher pulse repetition settings with less fragment migration, resulting in a decrease in operative time, costs, and the need for additional procedures to treat residual fragments (14, 50).

CONCLUSION

Lasers represent a spectrum of extremely useful tools in the urologists armamentarium. Despite the common label of "laser" however, each type has its own unique properties and indication. Knowledge of these properties optimizes patient treatment and safety. As lasers, and the devices used to deliver and aid in their utilization improve, the spectrum of indications for lasers will not doubt increase, allowing urologists to offer additional minimally invasive treatment options to their patients.

Abbreviations

Nd: Neodymium
YAG: Yittrium–aluminum–garnet
KTP: Potassium-titanyl-phosphate
Ho: Holmium
TUR: Transurethral resection
TURP: Transurethral prostate resection
PVP: Photovaporization of the prostate
BPH: Benign prostate hyperplasia
UPJ: Ureteropelvic junction
EPS: Endoscope protection system

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