Holmium Laser in Endourology

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Werner Falkenstein
StarMedTec GmbH, Starnberg, Germany

Summary

A holmium laser is a pulsed laser system with a wavelength of approximately 2 µm with absorption properties midway between those of a Nd:YAG laser and a CO_2 laser.

By choosing suitable laser parameters, the laser can easily be adapted to the application intended. It is equally suitable for athermal ablation of hard and soft tissues and for lithotripsy, regardless of the color or composition of the calculus.

In particular medium-power (30–40 W) holmium laser units are ideally suited for today's endourology thanks to their wide range of applications, their effective and safe use, and their comparably favorable capital investment requirements and running costs.

Key words: holmium laser, endourology, lithotripsy, strictures, BPH, LITT, enucleation, TURP, prostate.

Introduction: Characteristics of Holmium Lasers

For some years now holmium lasers have been available for endourological applications [1,2]. Like the Nd:YAG laser the holmium is a solid-state laser operating in the infrared segment of the spectrum, except that its wavelength of 2 µm is twice as much of an Nd:YAG laser of 1 µm.

While Nd:YAG lasers are characterized by low water absorption and their ability to deeply penetrate the tissue, the wavelength of the holmium laser beam is easily absorbed by water, so its depth of penetration, at approximately 0.4 mm, is therefore low. Being a pulsed laser with a pulse duration of several hundred microseconds and high absorption in tissue, the effect of a holmium laser is restricted to the area close to the fiber tip. It creates a minimal zone of coagulation around the treatment area of approximately 0.5 mm – large enough to prevent bleeding in most cases and to facilitate hemorrhage-free procedures. A satisfactory cutting effect can be achieved by using repetition rates starting at 15–20 Hz. Furthermore, the water content of uroliths and other calculus turned out to be high enough for adequate energy absorption; therefore calculi can be destroyed regardless of their color, hardness, or composition.

Laser	Wavelength (nm)	Absorbtion coefficient (cm -1)	Coagulation zone (mm)
Nd:YAG	1064	0,55	4–18
Ho:YAG	2080	30	0,4
Er:YAG	2940	12500	0,04
CO2	10600	995	0,125

Table 1 Absorption properties of different laser systems in water [3]

The effect of holmium laser radiation is the same in tissue and in calculus:

A small volume of water is irradiated by the laser and heated extremely rapidly to several hundred degrees Celsius. The hyperthermic water is converted to steam, expands explosively and takes with it fragments of the tissue or calculus. Since not all of the tissue or calculus to be removed must be heated and vaporized, this laser application is highly efficient. In fact, this type of removal can be called athermal, since the heating process is restricted to the actual absorption volume, leaving surrounding tissue unaffected. This procedure is called ablation.

Moreover, the holmium laser parameters can be varied to enable coagulation effects similar to those of a Nd:YAG continuous wave laser to be created using low pulse energy and high repetition rates and maintaining a greater distance between the fiber end and the tissue.

To examplify this: The energy of a typical laser pulse for tissue ablation is 1 J. This corresponds to the amount of energy that a light bulb with a rated output of 5 W for the parking lights on a car will emit within 0.2 seconds and that is just about to warm a human hand. Owing to the short pulse duration of e.g. 200 µs, nevertheless, this produces a remarkable peak pulse power of 5 kW, with the power density at the end of a fiber with a core diameter of 400 micrometers reaching a value of 4 MW/cm². In practice, peak pulse powers of up to 15 kW and power densities of up to 10 MW/cm² are achieved. These values for energy and power density are ideally suited for tissue ablation and for lithotripsy of all kinds of calculus.

However, if the pulse energy used is 0.2 J and the distance between the fiber end and the tissue is 4 mm, the power density will not reach the value required for tissue removal (20 J/cm²) [3], and straight coagulation is the result. The energy and power density values cited will not exceed the typical destruction thresholds (of approximately 200 MW/cm² for quartz-glass fibers) even at noticeably higher energy levels (a factor of more than ten), and therefore the energy is transmitted without any problems. The water content of these transmission fibers is significantly reduced compared to Nd:YAG laser fibers (low-OH fibers).

Energy	200–3500 mJ
Puls width	350 / 200-600 µs
Repititon rate	3–50 Hz
Power	15–100 W
Power requirements	110 V / 15 A – 230 V / 30 A
Device cooling	Internal water air heat exchanger

Table 2 Typical holmium laser parameters

In addition to fibers with smooth ends, known as bare fibers with core diameters of between 200 and 1000 µm, there are also applicators featuring specific tip configurations such as side-fire fibers for tissue ablation or laser-induced thermotherapy (LITT) applicators for interstitial thermotherapy.

Thinner highly flexible fibers are used in flexible endoscopes, thicker fibers in rigid endoscopes, being able to transmit a great amount of laser power. The typical parameters of holmium lasers are listed in table 2.

More recent holmium laser systems work with variable pulse durations. Short pulses increase lithotriptic efficiency, whereas long pulses enhance coagulation. Varying the energy, the pulse duration, and the repetition rate, the holmium laser's radiation can be ideally adjusted to the intended purpose.

Since the fiber tip is located close to or in direct contact with the calculus or tissue, the effect is limited to the irradiated site. Reflected light is effectively absorbed by surrounding water protecting adjacent regions. Used under visual control, the treatment method is safe and easy to learn.

Low-, Medium-, and High-Power Holmium Lasers: What are the Differences?

Low-Power Holmium Lasers (10–20 W)

The main application of these laser systems is lithotripsy, subject to certain restrictions regarding large and/or very hard calculus. Due to the typical low repetition rates (< 12 Hz) and energy values (< 2 J) many tissue-related applications with the laser systems tend to be lengthy in nature and difficult to perform. Taking the original investment and the running costs into consideration, low-power holmium lasers must be currently considered as relatively expensive, regarding especially their limited field of application.

High-Power Holmium Lasers (60–100 W)

These laser systems are extremely powerful – often more powerful than necessary. Most endoscopic applications other than lithotripsy rarely require more than 30 W, except for enucleation of the prostate and laparoscopic resection. In practice, only a few centers can afford the high costs of purchase, which are usually three times more than the one reqiured for low-power laser systems. Moreover, the high running costs and a reasonable profit are rarely generated during operations. The high costs are caused, among other reasons, by increased expenditures for maintenance, since the power generated by these systems requires three to five laser heads to be integrated in a single housing and the radiation emitted to be bundled into a single fiber by a laborious process using multiple optical components. Furthermore, these laser systems require a multiphase high-voltage power supply, which is not available everywhere. Room climate must be considered too as the electrical energy expended (approximately 5–6 kW) is converted to heat.

Medium-Power Holmium Lasers (30–40 W)

Medium-power laser systems are an interesting alternative to the low-power and high-power laser systems described. They cost only slightly more than low-power laser systems, but can be used for a wide range of endourology applications. Procedures that can be performed include lithotripsy as well as other soft tissue and hard tissue applications and the enucleation of the prostate, although the latter may be subject to certain restrictions due to the slightly extended time required for the procedure. This laser will work with a standard power supply (230 V / 16 A) as available everywhere.

Clinical Applications of Holmium Lasers

Lithotripsy

The most frequent applications are ureteroliths (ureteral calculus) and nephroliths (renal calculus) – the latter especially as a follow-up after extracorporeal shock wave lithotripsy (ESWL). Smaller cystoliths (bladder calculus) (fig. 1) belong to the field of application too.

Strictures

Strictures in the narrower sense of the term are constricted segments of the urethra or the ureter. More generally, they include other stenoses of the urinary system, whether at the outlet of a kidney or the neck of the bladder caused by an enlargement of the central lobe of the prostate in BPH. In these cases a short incision into the obstruction is carried out with the laser, a procedure called endopyelotomy (for a kidney) or bladder neck incision.

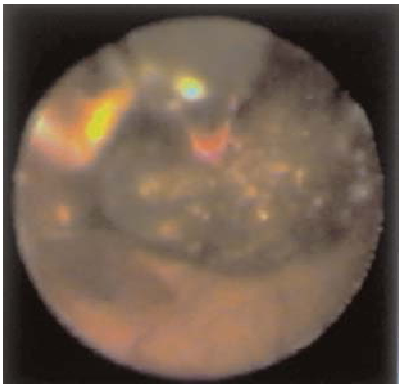

Fig. 1
Ureter stone
with laser fiber

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The following illustrations (fig. 2 and 3) show the cutting action of the holmium laser in urethral stricture. The incision draws no blood. It is surrounded by a coagulation zone of low but adequate thickness, which is discernible by its white color. Urethral strictures can usually be treated on an outpatient basis under local anaesthesia. An early publication indicates a markedly reduced rate of recurrence using the holmium laser system in comparison to the conventional approach. [4].

Benign Prostatic Hyperplasia (BPH)

Depending on the severity of the condition, different types of procedures can be performed with the holmium laser treating BPH (fig. 4). Smaller obstructive enlargements of the central lobe will often result in an obstruction of the bladder neck, which can be treated with a bladder neck incision (figs. 5 and 6) as mentioned before.

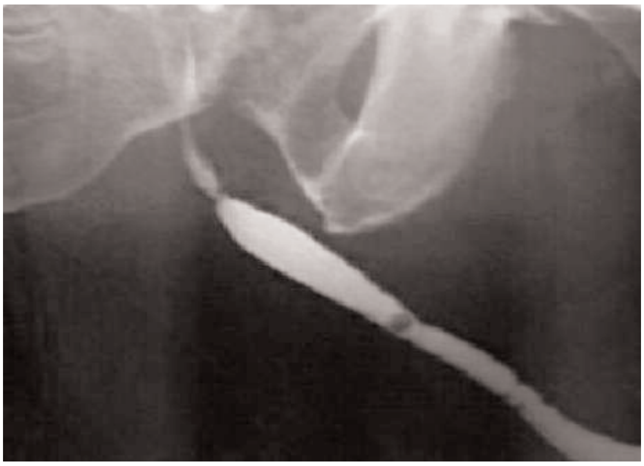

Fig. 2 Radiograph urethral stricture
Prof. Dr. Köhrmann, Mannheim

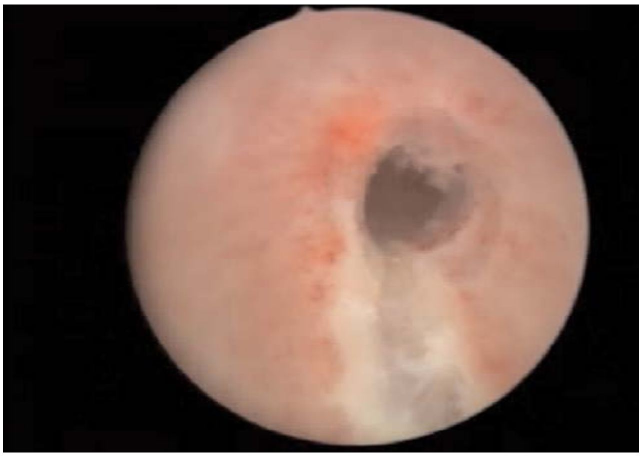

Fig. 3 Endoscopic picture: urethral stricture
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Partial ablation (HoLAP) can be performed on obstructive prostates weighing between 20 and 50 g. At present great efforts are made to market the KTP laser, a frequency-doubled Nd:YAG laser, in addition to the Ho laser. By comparison, however, it shows that around 1 g/min of prostatic tissue can be ablated independingly of the procedure used. As opposed to published results for photoselective vaporization of the prostate using the KTP laser at 2 g/min, in many cases only a part of the prostatic tissue is removed in this procedure. Internal data have also yielded the same value of 1 g/min for this procedure.

Mid-size prostates as well as large prostates (> 50 g) can be enucleated (HoLEP) (Fig. 7). In this procedure larger parts of the prostatic lobes are enucleated all the way to the capsule and deposited in the bladder, where they are subsequently destroyed with a tissue morcellator and then removed by suction. After two incisions at five and seven o'clock positions the central lobe is removed to gain space followed by removal of the two lateral lobes. Special about this procedure is that no cuts across the prostatic tissue are required except the initial incisions and the incisions to remove the enucleated lobes. This is the only phase in which high laser power would result in actual gain of time. On the contrary, approaching from below, the prostatic lobe is mechanically lifted by the tip of the endoscope, and only those few fibers connecting the prostatic tissue with the capsule are severed by the laser.

Fig. 4
Benign prostatic hyperplasia

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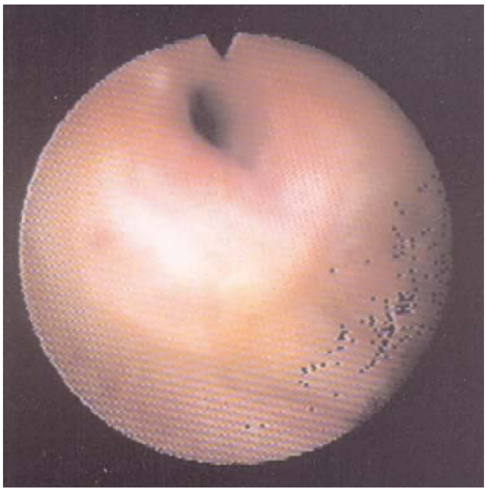
Gilling (5)	1,31 g/min	HoLAP:Ho:YAG (60 W)
Gilling (6)	1,84 g/min	HoLAP:Ho:YAG (80 W)
AURIGA (WLT)	~ 1 g/min	HoLAP:Ho:YAG (30 W)
Malek (7)	~ 1 (2*) g/min	PVP:KTP (80 W)
Marberger (8)	1,16 g/min	TURP

Table 3 Erosion rates of different laser procedures in comparison to the TURP



Figs. 5, 6 Bladder neck incision
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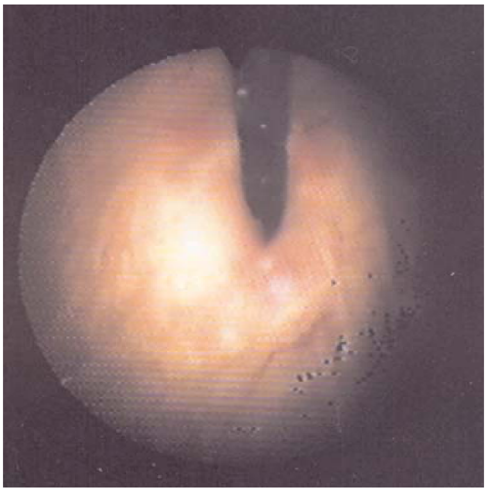

According to this it could be shown that this enucleation technique was also feasible at 30 W of laser power, although with slightly more time involved. This sounds simple, but taking into account that incisions must be made three-dimensionally within a very constrained space and with high precision using a long endoscope, it becomes obvious that the learning curve is quite slow.

An evaluation of a relatively large number of randomized studies on laser prostatectomy versus TURP [9] revealed that lasers and particularly holmium lasers using the contact procedure (HoLEP) exhibited comparable or even better values than TURP, especially when it comes to improving symptoms / peak flow, with reduced hospitalization periods, shorter catheter indwelling times, a reduced need for blood transfusions, and

Fig. 7 Principle of the enucleation of the prostate (HoLEP)
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fewer iatrogenic strictures. Transurethral resection (TUR) syndrome caused by massive absorption of irrigating liquid by living tissue never occurs.

In high-risk patients a special applicator can be used to perform a LITT procedure (figs. 8 and 9), if necessary followed by a TURP [10,11], which thus can be performed quickly, safely, low on adverse reactions, and bloodlessly in denatured tissue without risking TUR syndrome.

In this context TURP must be still considered as the gold standard in BHP treatment, although the morbidity rate at approximately 18 % is relatively high yet.

The laser procedures described establish additional therapeutic avenues with clearly reduced morbidity, creating for patients new alternatives beyond TURP, depending on the severity of the disease, the patient's personal situation, and lifestyle.

	Ho:YAG-Kontakt	TURP
Improvement of symptoms	79 %	81 %
Improvement of peak flow	175 %	128 %
Average hospitalization period (days)	1,4	2,6
Average catheter indwelling time (days)	1,5	1,9
Necessity of blood transfusions	1 %	7 %
Iatrogenic strictures	0–7 %	8 %

Table 4 Comparison holmium laser prostatectomy versusTURP (9)

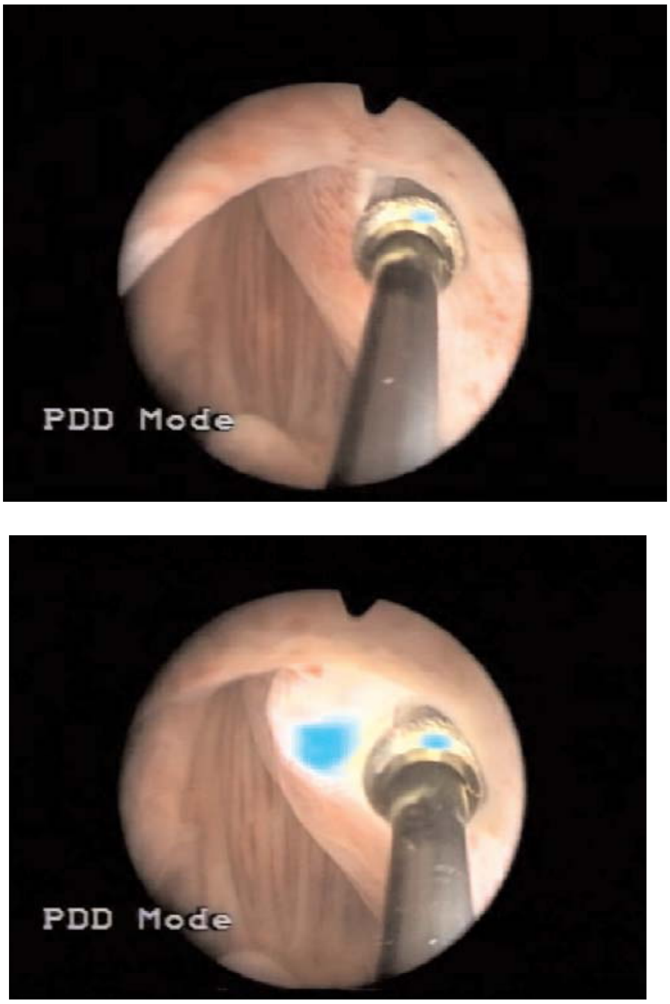
Using the Holmium Laser in Clinical Practice

Twelve Months Data using a Medium-Power Laser

Since early 2002 the AURIGA holmium laser system (fig. 10; StarMedTec GmbH, Starnberg, Germany) has been used at the Heilbronn University Hospital (director: Professor Jens Rassweiler).

The laser's maximum power is 30 W, with pulse repetition rates of up to 20 Hz. In addition, the duration of the individual pulse is automatically adjusted between 200 and 600 µs depending on the selected treatment mode. Thus the device can be used efficiently for all endourological applications such as lithotripsy, tissue ablation and coagulation, incisions, and for prostate enucleation.

The energy is transmitted by fibers of 230, 365, 600, or 800 µm. Special applicators such as side-fire or LITT applicators are available. The system makes no special demands on the power supply; a standard 230 V / 16 A outlet will do. As a result of its compact design the unit can be easily moved and therefore used in three different operating theaters according to the OT schedule.



Figs. 8, 9 LITT with the holmium laser
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Results:

Within a period of twelve months the laser unit was in use for the indications as follows:

52	ureteroscopic laser lithotripsies
35	laser urethrotomies (urethral strictures)
21	transurethral laser enucleations of the prostate (HoLEP)
18	laser endopyelotomies
10	bladder neck incisions
10	ureteroscopic tumor vaporizations

Compared to previous experiences with Nd:YAG lasers in the treatment of strictures and tumors, the holmium laser proved to be superior with regard to its suitability for ablation and incision. This superiority is mainly based on the non-thermal ablation effect of the pulsed holmium laser, which also allowed the therapy of urethral strictures under local anaesthesia with significantly less pain than by the thermal Nd:YAG laser caused.

With regard to HoLEP the following was noted:

Adenomas up to 120 g could be enucleated. However, this was a technical and surgical challenge, especially with large prostates (> 80 g). In addition, the destruction of adenomas using various tissue morcellators proved to be unsatisfactory. For this reason laser enucleation is currently combined with bipolar morcellation of subtotally enucleated prostatic lobes.

Fig. 10
Holmium laser AURIGA, StarMedTec GmbH Starnberg

The advantage of this includes the performance of adequate enucleation in line with the state of the art in laser enucleation technology; the same holds for morcellation using the bipolar resectoscope and regular saline as an irrigant. In this way it is possible to avoid TUR syndrome even with extended operating times of up to 120 minutes.

Since this system has been applied, neither the Nd:YAG laser nor the dye laser (for lithotripsy) are in use anymore.

Treatment of ESWL-Refractory Ureteral Calculus

Over a period of twelve months the AURIGA holmium laser system (WaveLight Laser Technologie AG, Erlangen, Germany) was used at Mannheim University Hospital to treat among many other patients a total of 27 patients with ESWL-refractory ureteral calculus [12]. The results are depicted in table 5.

Conclusion

It could be demonstrated that the holmium laser with its application under direct vision is a safe instrument, and a very versatile too as it can be used for destroying stones as well as for different soft and hard tissue applications as for cutting, ablation, and coagulation. In summary it may be said that especially the holmium laser of medium-power covers a variety of endourological applications. It is effective and safe in application, economic in acquisition costs and maintenance, and in line with the indication of the DRGs it particularly represents the optimal equipment for modern endourology.

Total number of ESWL patients	362
Number of refractory stones	27
Localisation of stones: prox. / approx. HL	21
Kidney	5
Stone size (approx.)	6 – 20 mm (11,6 mm)
Composition of stone	74 % ca-oxalat (> 80%)
Laser energy	600 – 1400 mJ
Number of laser pulses (approx.)	2589
Total stone desintegration	28 pat. / 93 %
Stone free rate after treatment	14 pat. / 53 %
Partial stone desintegration	2 pat. (19 respectively 20 mm; re-ESWL)
Post-operative stay in hospital	1,8 Tage (approx.)

Table 5 Results of the holmium laser treatment ESWL-refractory stones (12)

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Dr. Werner Falkenstein
WaveLight Laser Technologie AG
Bereichsleiter Chirurgie
falkenstein@starmedtec.com