What is new in lasers for endourology: looking into the future

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From the first cystoscopic argon and neodymium-YAG (yttrium-aluminium-garnet) laser used for bladder tumours in 1976 by Staehler et al. [1], lasers have proven to be a versatile and an evolving tool in the therapeutic management of a variety of urological diseases, including benign prostatic hyperplasia (BPH), kidney stone disease (KSD), urinary strictures, bladder and penile tumours [1-4]. Lasers have allowed minimisation of procedures to help safely treat an ageing population with multiple co-morbidities resulting in shortened

anticoagulant interruptions, less invasive procedures and reduce hospitalisation time [2].

The application of lasers in endourology has broadened in the past three decades due to numerous advancements in laser technology, equipment, settings and the associated costs [3]. The need for thin and flexible yet durable and precise delivery systems has led to the development of specialised instruments for endourological surgery. Improvements and education of laser safety and related complications has increased the availability and usability of

a variety of laser types and techniques; however, the high cost of newer laser technology can limit its more regular usage in urology departments. Here we look at the lasers currently used in endourology and take a sneak peek at the newcomers in this technologically developing field.

Type of lasers

All lasers consist of an energy source, an active medium, and a resonant cavity. The energy source simultaneously brings the atoms or molecules within the active medium to a higher energy state, referred

Table 1: An overview of current and previous lasers used in endourology

Laser type	Use	Technical aspect	Benefit	Disadvantages
Nd:YAG (neodymium-doped yttrium aluminium garnet)	- Ablation and coagulation of prostate - Upper tract lesions - Urolithiasis	- Wavelength 1064nm ~2000W - Coagulates tissue to depth of 5-10mm	- Safe in anticoagulated patients - Contact mode vapourisation - Low thermal effects to ureter	- Irritative LUTS & urinary retention due to delayed sloughing - Difficultly in fragmentating 'hard' stones
KTP:YAG (potassium titanyl phosphate)	- Photoselective vapourisation of prostate (PVP) - Bladder neck incision	- Doubled frequency of Nd:YAG so shorter absorption depth - 'High-power' output of 80W - Good haemostasis	- Virtually bloodless procedure - Reduced catheterisation rates	- Temperature increase of tissue not sufficient for vapourisation - Scattering seen through coagulated layers and reduction in intensity
LBO:YAG (lithium borate)	- PVP	- Wavelength (532nm) within the visible green region - Maximum average power 120W - Increased working distance (up to 3mm)	- Faster energy transfer and tissue ablation - Can be used to treat larger prostate glands	- Reduction in haemostatic ability
Holmium (Ho):YAG	- Prostate enucleation - Ablation of urothelial tumours - Strictures of upper and lower urinary tract	- Pulsed laser with wavelength of 2140nm - Small absorption depth (0.4mm) - Simultaneous coagulation of small blood vessels	- Minimal retropulsion effects during stone fragmentation - Able to fragment all stone types - Small penetration depth safer for small ureteric tumours	- Requires direct contact of laser tip with stone
Thulium (Tm):YAG	- Prostate enucleation - Optical urethrotomy - Laser lithotripsy	- Improved vapourisation ability allowing larger prostates to be treated - Penetration depth 0.3mm	- Very little injury to surrounding tissue	
Diode	- Prostate vaporisation - Bladder TCC	- Wavelength 810 to 1064mm - Lower power - Penetration depth 1-3mm	- Good haemostasis - Smaller box size compared to Nd:YAG laser	- High incidence of complications and postoperative irritative symptoms
CO²	- Laser tissue soldering for skin anastomosis of skin - Laser ablation of penile and genital skin lesion	- Beam of infrared light (wavelength 9.6 and 10.6 m) - Most efficient and powerful of all continous wave laser devices	- Highly efficient with high output powers - Cutting & haemostasis achieved photo-thermally	- Risk of dispersion of oncogenic virus in aerosol

to as pumping. The active medium of a laser is what determines its wavelength and frequency, and may be a solid, liquid or gas. Various active mediums used over the years have ranged from gases such as nitrogen, carbon dioxide, and helium to liquids such as neon dye lasers. The latter uses a solution containing a complex organic dye; the choice of dyes enables production of laser light over a broad range of wavelengths. Solid active mediums such as neodymium-doped yttrium-aluminium-garnet (YAG) were developed in the 1960s and are still in use today [4]. An additional internal or external accessory device can be added to convert the output to visible or ultraviolet wavelength. Semiconductor, also known as diode lasers, are made up of two semiconductor material layers. Despite being small and of low power, they can be combined to create larger, more powerful versions. Common endourology lasers include the Holmium (Ho:YAG), Potassium titanyl phosphate (KTP: YAG), commonly referred to as the 'green light' laser, and Thulium (Tm:YAG and fiber (TFL)) lasers.

Controllable parameters

Settings such as pulse energy, frequency, width, power and fibre sizes are factors that can impact the efficacy and safety of a laser. Many studies have looked into understanding these technical factors and how they can be used to optimise the use of lasers and reduce complications. Other characteristics of different lasers that need to be taken into consideration include penetration depth, thermal effects and scattering of light energy. The amount of localised thermal damage, absorbed laser light and absorption depth of each laser is of clinical significance. This is a function of the wavelength and power density of the laser and the absorption coefficient of the tissue. An overview of currently used lasers, their application, benefits and disadvantages can be found in Table 1.

High power Ho:YAG and MOSES technology

The Ho:YAG laser is a multi-functional laser that has been reliably used for over 20 years in endourology. The 2140nm wavelength is

strongly absorbed in water, which means it travels only about 0.3-0.5mm in a fluid medium, making it ideal for urological use within a limited space such as the ureter or renal pelvis. A higher pulse frequency Ho:YAG laser (HPL) resulting in a higher energy output (100/120W) has been studied for use in retrograde intrarenal surgery (RIRS) [5]. It can be used for stone fragmentation, dusting, pop-corning and pop-dusting by changing the energy and frequency settings (Table 2). Whilst the high energy and low frequency settings are used for fragmentation, low energy and high frequency settings are used for dusting. In pop-dusting, a low energy beam in a contact mode is used first to break down the soft outer shell of a stone, then switching to a higher energy beam in a non-contact mode to 'pop' the hard core into dust, all of which can then be passed spontaneously. This method also reduces the number of treatments needed for large stones: in one study 93% of patients were stone-free after one treatment [6]. HPL is more expensive than the existing low-power Ho:YAG, which are the most commonly used in stone surgery

Table 2: Summary of laser properties for lithotripsy (adapted from Kronenberg P, Somani B. Advances in lasers for the treatment of stones - a systematic review. *Curr Urol* Rep 2018;19(6):45).

	Advancement or Technical aspect	Benefit	Verdict
Laser lithotripters	Long pulse length (pulse duration or pulse width)	• Less fibre tip degradation • Less stone retropulsion • Smaller residual fragments • Ideal for 'dusting'	• Gradual rise in its use
	Moses effect (modulated laser pulse)	• More ablative (in-vitro) • Less retropulsion	• No significant difference between lasing and procedural time in-vivo • Limited availability • Costly
	Burst laser lithotripsy	• Greater ablation volume	• Likely to be used more often • Limited availability
Laser settings and technique	Fragmentation technique (High energy low frequency)	• Faster ablation of primary stone	• Excellent for bladder or PCNL
	Dusting technique (High frequency low energy)	• No fragments (dust) • No basketing • Decreased ureteral access sheath use	• Ablation itself takes more time, compensated by other time gains • Ultra-high frequency lithotripters further shortens surgical time
	Pop-corning	• Ideal for multiple smaller stone fragments in an enclosed space • Avoids endless chase of fragments	• Helpful technique, complementing other lithotripsy methods
	Pop-dusting	• Similar to pop-corning, but creating more dust	• Helpful technique, complementing other lithotripsy methods
Laser safety and related complications	**Complication**	**Prevention**	
	Fever, subcapsular haematoma	• Reduce operative time • Use low pressure ureteroscopy • Confirm negative urine culture	
	Local thermal damage	• Never close irrigation • Intermittent laser use • Cooled irrigation if necessary	
	Eye damage	• Use safety goggles • Avoid laser fibres near eyes	
	Collateral instrument damage	• Keep fibres coated for better identification and regularly cleave them • Respect the safety distance between scope and laser fibres tip	

currently, but this cost is likely to be balanced out by reducing the need for completion or secondary procedures.

Changing the settings such as pulse energy, frequency and pulse width can affect the power output of the laser and so it can be readily tailored towards different functions. A new dual-phase MOSES 'pulse modulation' technology has been introduced in high-power laser machines. Patented by Lumenis, MOSES pulse technology works to modulate the pulses into two peaks; the first separates the water and the second targets the stone through the bubble created by the first peak [7]. This aims to improve stone fragmentation without the increased stone retropulsion which is seen with high power Ho:YAG lasers, saving time and increasing efficiency. Studies have shown a 20% reduction in procedure time and a 50% reduction in stone retropulsion [7].

Thulium lasers

Thulium:YAG laser (Tm:YAG) is already established as an effective method of prostate vapourisation and enucleation. This differs from Ho:YAG in that the energy source which excites the thulium ions are from high-power laser diodes, which means there is less heat generation and increased power generation by a factor of five. Recent newer application of thulium laser technology has renewed interest in this for KSD. Super-pulsed thulium fibre lasers (TFL) use electronically modulated laser diodes allowing delivery of a higher and more constant peak power with a wider range of laser parameters through a fibre [8]. Water absorbs TFL energy approximately four times higher than Ho:YAG, and hence its optical penetration depth in water is four-times shorter than the Ho:YAG laser, resulting in lower stone and tissue ablation thresholds [9]. Smaller laser fibre sizes allow low pulse energy to be delivered with a very high pulse frequency thus minimising inadvertent surrounding tissue damage, giving this laser ideal physical properties for stone lithotripsy and prostate enucleation [10]. Studies are ongoing to fully understand the benefits as well as limitations of these lasers.

Laser fibres

The fibres themselves are an important and emerging concept in laser design. The need for thin, flexible lasers that don't compromise on intensity or durability are vital in endourology. With miniaturisation of instruments, the diameter of fibres (made up of the fibre core and two to three outer layers) need to fit in a working channel alongside irrigation flow. The choice of outer layer cladding material (the majority are silica) determines the bending radius

allowing for curvature. It can also affect the amount of undesirable attenuation and leakage resulting not only in reduction of power but damage to the scopes themselves. Wear and tear, whether inadvertently or due to excessive bending can cause radiation leakage as well as explosive fibre failure. The balance seems to be between a thin, flexible fibre which provides a higher laser intensity at the distal tip but is robust enough to prevent breakage and regular (costly!) replacement. Side firing tips are also available and offer an increased beam expansion at the tip and better control on the point of impact.

Conclusion

'With great power comes great responsibility' – increased tissue injury, more stone retropulsion, sub-optimal results, and a larger repair bill! The future of lasers in endourology isn't all about power and recent studies have focused more on power delivery methods, pulse optimisation, techniques, equipment size and durability. The increased use of lasers on a day-to-day basis requires knowledge and clear understanding of how lasers work and how adjusting the settings of a laser can significantly change its characteristics to adapt it to specific urological applications. Lasers are one of the safest tools in endourology and newer developments in this technology will allow further minimisation and increased efficacy and safety of endourological procedures with exciting new developments in the future.

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TAKE HOME MESSAGE

- Lasers are an evolving and vital tool in the therapeutic management of a variety of urological diseases.

- Most common procedures include intrarenal lithotripsy for kidney stone disease and ablation and vapourisation of the prostate in BPH.

- High energy and low frequency settings are used for stone fragmentation; low energy and high frequency settings are used for stone dusting.

- Ho:YAG laser is the current gold-standard for stone disease and with the addition of new dual-phase MOSES 'pulse modulation' technology it has improved stone fragmentation without increased stone retropulsion.

- The newer thulium fibre lasers appear to be superior in terms of fragmentation speed, particle size, retropulsion distances and portability but currently lack supporting data from clinical trials.

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