Laser in Urology

Principles, types and utilization (Soft tissue and Stones)

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Definition and Principles

• Light Amplification by the Stimulated Emission of Radiation.\(^1\)

• High-intensity light which bombards a resonator cavity with photons.

• Excites electrons in the resonator cavity to a higher energy status.

• Instability of excited state orbitals leads to rapid decay of electrons.

• Very rapid decay of electrons emit a photon.

• Energy released spontaneously in the form of photons or electromagnetic (EM) waves to return to the ground state.

1-Nau et al,2000
Definition and Principles

• Spontaneous emission of radiation.

• Emitted photons interact with other excited state atoms.

• Amplifies electron orbital decay and photon emission.

• This photon has similar characteristics and travels in the same direction as the incident photon.

• Leave resonator cavity as a coherent laser beam.
Laser Principles

• Coherence – the photons are all in phase.

• Collimation – they travel parallel with no divergence.

• Monochromaticity – they all have the same wavelength and, therefore, the same color if within the visible light spectrum.

• Different lasing mediums (solid, liquid, or gas) emit photons in different wavelengths of the EM spectrum.
Laser Principles

• Continuous vs. Pulsed.

• Pulsed wave has more precise control and less lateral heat conduction to tissues.

• Factors affecting laser-tissue interactions:
  - Local tissue properties.
  - Local blood circulation.
  - Laser wavelength, energy and mode.

• Molecules, proteins, and pigments may absorb light only in a specific range of wavelengths.
Types of Laser

• Neodymium : Yttrium-Aluminium-Garnet (Nd:YAG)

• Potassium-Titanyl-Phosphate (KTP)

• Holmium: Yttrium-Aluminium-Garnet (Ho:YAG)

• Diode Laser
Nd : YAG

• Emits light at wavelength 1064nm.
• Neodymium atoms in yttrium-aluminium-garnet rod.
• Poorly absorbed by water and body pigments.
• Penetrate tissue relatively deeply.
• Causes thermal coagulation of surface tissue / under surface.
• Coagulated tissue sloughs and healing may take up to 3 months.
• Modification with tissue vaporization and dessication.
• Requires higher energy density for a longer period of time.
• Surface carbonization leads to increased laser light absorption superficially and less depth penetration.
• Increased energy density.
Potassium-Titanyl-Phosphate

- Uses KTP crystal to double the frequency of Nd:YAG laser.
- Wavelength 532nm.
- Intermediate level of coagulation and vaporization.
- Tissue penetration half of Nd:YAG.
- Higher energy per unit tissue volume increase tissue vaporization and dessication.
- Advantage – prostate abd bladder neck may be incised with KTP laser.
Holmium: Yttrium-Aluminium-Garnet

- Emits light at frequency 2100nm.
- Series rapid pulses over a few milliseconds, the Q switched laser.
- Unlike continuous wave of Nd:YAG and KTP laser.
- Different flexible optical fiber required.
- Cutting effect by vaporization of the tissue water.
- Less hemostatic properties than continuous wave lasers.
Diode Laser

• With conventional lasers, less than 5% of the electrical input converted into laser light.

• Inefficient.

• Requires high-energy cooling devices and radiators.

• Diode laser allows more efficient use of the photons.

• Small and portable device with no special connections.
Methods of Delivery

• End firing
  - Bare tip
  - Sculptured tip
  - Sapphire tip

• Side firing
  - Metal of glass reflector
  - Prismatic internal reflector

• Interstitial
  - Baretip
  - Diffuser tip
  - Diffuser tip with temperature transducer
Methods of Delivery

• Energy levels determine coagulation or evaporation.
• 45c to 50c - tissue dessication.
• 50c to 100c – coagulation.
• >100c – tissue boils with carbonization and vaporization.
• Vaporization causes tissue water converted to steam and miniexplosions occur within tissues.
• Increases mechanical rupture.
• Laser intensity, not duration determine vaporization.
• Once coagulated, laser energy penetrate less well.
• Halts forward ablation and increasing backscatter and surrounding coagulation.
Utilization in Urology – Soft Tissue

• Effect on the prostate – coagulation(70c to 90c) or vaporization.
• Nd:YAG supplies wide scatter of power over relatively large surface area with deep penetration.
• Vaporization (>100c) occurs through high power density delivered by a narrow beam.
• Coagulation or vaporization determined by power density, total energy, and duration of application.

• TULIP device (transurethral ultrasound-guided laser-induced prostatectomy).
• 7.5MHz ultrasonic transducer at the tip and Nd:YAG laser.
• Indirect visualization by ultrasound.
Utilization in Urology – Soft Tissue

• Visual laser ablation of the prostate (VLAP)
  - Side firing system with a mirror to reflect or a prism to refract the laser at various angles (usually 90) from a laser fiber located in the prostatic urethra onto the prostate.
  - Coagulation with subsequent necrosis.

• Contact laser prostatectomy
  - Greater degree of vaporization than VLAP, allowing immediate removal of tissue.

• Interstitial laser prostatectomy (ILP)
  - Transurethral placement of laser fiber directly into the prostate.
  - Produces a zone of coagulative necrosis some distance from prostatic urethra.
Laser Prostatectomy

- Several laser prostatectomy evolved during the 1990’s

- TULIP, VLAP, contact laser prostatectomy and ILP have been succeeded by holmium laser prostatectomy.

- Green light laser recommended use only in the context of RCT
KTP Laser Vaporization of the Prostate

• ‘Greenlight’ photoselective vaporization of the prostate (PVP).
• YAG laser shone through a KTP crystal.
• Doubles the frequency halves the emitted wavelength to 532nm.
• Green part of visible spectrum.
• Strongly absorbed by hemoglobin.
• Prostate tissue vaporization so no tissue for HPE.
• KTP energy poorly absorbed by water/saline.
• Non-contact vaporization possible.
KTP Laser Vaporization of the Prostate

- Benefits
  - Less heating of the delivery fiber.
  - Longer duration.
  - Laser heat concentrated over a small area with rapid tissue vaporization and minimal coagulation of underlying structures.
  - 2mm rim of coagulated tissue.
  - Effective hemostasis so can be used for larger prostates (>100mL) and higher risk patients on anticoagulants.(1)

1- Sandu et al, 2005
KTP Laser Vaporization of the Prostate

• Indications
  - 2010 NICE Guidelines.
  - Should only be offered as part of an RCT.

• Advantages over TURP
  - Day surgery operation.
  - May not require catheter post-op/ removed within 24 hours.
  - Virtually bloodless operation.
  - Lower incidence of retrograde ejaculation.(1,2)
  - Equivalent short term efficacies, but significantly shorter catheterization times and inpatient stays in the laser group.(3)

1-Sandhu JS et al, 2005
2-Sarica K et al, 2005
3-Bachmann A et al, 2005
Holmium : YAG Laser

• Pulsed solid state laser.
• Wavelength 2140nm, strongly absorbed by water.
• Absorbed into prostate tissue to 0.4mm depth.
• Heat created (>100c) causes good tissue vaporization with coagulation of small to medium sized vessels.
• Coagulative depth 2-3mm beyond the vaporized tissue.
Holmium Laser Enucleation of the Prostate (HoLEP)

- Useful for larger prostates (>40g).(1)
- End-firing laser fiber cut grooves into the prostate down to the capsule.
- Prostate lobes dissected, pushed into the bladder, fragmented and aspirated.
- At least equivalent to TURP with fewer associated risks.
- Shorter catheterization time and hospital stay.(2)
- Sustained significant improvement in symptom scores and flow rates.(3)

2- Wilson LC et al, 2006
3- Elzayat EA et al, 2005
Holmium Laser Ablation of the Prostate (HoLAP)

- Side-firing dual wavelength fiber.
- Near-contact mode to vaporize prostate circumferentially.
- 60W to 100W laser.
- Sustained long term symptom improvements.(1)
- Shorter hospital stay, catheterization and less bleeding vs. TURP.(2)
- Most effective for smaller prostate glands.

1- Tan AHH et al, 2003
2- Mottet N et al, 1999
Holmium Laser Resection of the Prostate (HoLRP)

- Similar techniques to TURP.
- Cutting mode to remove pieces of prostate.
- Suitable for prostate glands of all sizes.
- Short catheterization times and hospital stay.
- Minimal post-operative dysuria. (1)

Laser Therapy for Bladder Cancer

- Minimally invasive ablation of tumors up to 2.5cm in size.
- Nd:YAG coagulates through protein denaturation using non-contact “free beam” laser up to 60W.
- Significant complication is forward scatter of laser energy to adjacent structures with risk of viscous organ perforation. (1)
- Limit to 35W, 60c minimize risks. (2)
- Most efficient delivery end-fire non-contact fiber with 5-15 degree angle and penetration depth up to 5mm. (3)
- More expensive.
- Bleeding negligible.
- No risk of obturator reflex.
- No tissue for HPE so most suitable for recurrent, low grade lesion with documented pathology.

1-Smith 1986a, 1986b
2Hofstetter et al, 1994
Laser Therapy for Penile Cancer

- Extensively evaluated for conservative treatment of penile squamous cell carcinoma.
- Potential advantage of eliminating primary tumor with preservation of surrounding tissues and penile function.
- CO2, Nd:YAG and KTP laser.
- Nd:YAG most commonly reported.(1-7)
- 3 to 6mm depth penetration, so suitable for small superficial lesions.
- Local recurrence rate for Tis and T1 with Nd:YAG alone is 20%.(8)
- Nd:YAG combined with surgical excision local recurrence rate 18% to 20%.(9)
- In general, laser therapy seems to be reasonable for Tis and small T1 squamous cell carcinoma of the penis and for T2 tumors who refuse more aggressive surgical treatment.

Laser Therapy for Urethral Strictures

- CO2, Argon, KTP, Nd:YAG, Ho:YAG and excimer lasers.
- Ideal laser should totally vaporizes tissue, with negligible peripheral tissue destruction, not absorbed by water, and easily propagated along a fiber.
- CO2 must be used with gas cystoscope with potential risk of CO2 embolus.
- Argon and Nd:YAG laser cause thermal necrosis with significant risk of peripheral tissue injury rather than vaporization.
- Nd:YAG carries risk of forward scatter.
- KTP and Ho:YAG both provide direct contact cutting and vaporization with minimal forward scatter.
- Results of laser urethrotomy are mixed.
- Ho:YAG may have a place in management of short and isolated urethral strictures.
Laser Lithotripsy

- Ruby laser in 1960’s effectively fragment urinary calculi but generated excessive heat and not appropriate for clinical use.(1)
- Coumarin pulsed-dye laser in 1980’s provide high power density with little heat dissipation.(2)
- Not effective for calcium oxalate monohydrates and cystine stones.(3)
- High cost and toxic disposables of coumarin dye.(4)
- 20 min start up time and require amber glass eye protection so difficult stone and laser fiber visualization.(4)

- Ho:YAG laser highly absorbed by water and results in superficial cutting or ablation.

1- Mulvaney and Beck, 1968.
2- Watson and Wickham, 1986
3- Coptcoat et al, 1988a.
4- Segura, 1999
Laser Lithotripsy

• Ho:YAG laser solid-state laser system.
• Superficial cutting or ablation.
• Zone of thermal injury 0.5 to 1.0mm.(1)
• 2140nm in the pulsed mode with pulse duration 250-350μs.
• Relatively long pulse duration produces an elongated cavitation bubble that generates only a weak shockwave.
• Stone fragmentation begins before bubble collapse and shockwave production.(2)
• Occurs primarily through a photothermal mechanism that causes stone vaporization.(3)

1- Wollin and Denstedt, 1998
2- Vassar et al, 1999
3- Dushinski and Lingeman, 1998
Laser Lithotripsy

- Holmium laser fibers available in 200, 365, 550 and 1000μm diameters with end or side-firing fibers.
- 200 and 365μm fibers used for flexible scopes.
- Lithotripsy with holmium laser depends on the pulse energy output and diameter of the optical deliver fiber.(1)
- Energy density increases with decreasing fiber diameter.(2)
- Pulse energies of 0.6 to 1.2J and pulse rates of 5 to 15Hz are used.(3)
- Start with low-pulse energy (0.6J) with pulse rate 6Hz and increase as needed.(4)
- Move the laser over stone surface in “painting” fashion to maximize efficiency and to vaporize it.(5)

1- Vassar et al, 1998
2- Calvano et al, 1999
3- Wollin and Denstedt, 1998
4- Spore ey al, 1999
5- Segura, 1999
Ho:YAG Laser Lithotripsy: Advantages

- Can transmit energy through flexible fiber.
- Safely activated 0.5 to 1.0mm from ureteral wall. (1)
- Able to fragment all stones regardless of composition. (2)
- Mean stone-free rate of 95%. (2)
- Mean perforation rate 1.1%, stricture rate 1.2%. (2)
- Produces significantly smaller fragments. (3)
- Produces weak shockwave and less retropulsion. (3)
- Eye protection does not compromise view of stone and laser fiber. (4)
- Machine more compact, minimal maintenance and 1 min. start up.
- One of the safest, most effective and most versatile intracorporeal lithotripters.

1- Santa-Cruz et al, 1998
2- Wollin and Denstedt, 1998
3- Teichman et al, 1998a
4- Segura, 1999
Ho:YAG Laser Lithotripsy - Disadvantages

- Initial high cost of device and laser fibers.
- Potential side effect is production of cyanide when uric acid stones are treated.
- A review of clinical experience suggests no significant cyanide toxicity from holmium laser lithotripsy. (1)

Ho:YAG in Laser Lithotripsy - Techniques

• Placement of fiber on the stone before laser is activated.
• Clear vision.
• Start at low settings and increase only as necessary.
• Short pause after initiation due to “snowstorm effect”.
• Holmium laser capable of cutting through metal.
• Laser fiber more than 2mm beyond tip of endoscope.
• At least 2mm from the urothelium.
Ho:YAG Laser Lithotripsy – Don’t

• Do not have one person controlling the fiber and another the foot pedal.

• Do not discharge the laser fibers inside the working channel or on guide wires and baskets.

• Do not pass the fiber tip through the back wall of stones.

• Do not be impatient.
Thank you.