Journal of Obstetrics and Gynaecology, April 2013; 33: 225–231

ISSN 0144-3615 print/ISSN 1364-6893 online
DOI: 10.3109/01443615.2012.747495

informa
healthcare

REVIEW

Laser technology and applications in gynaecology

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The term 'laser' is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers are commonly described by the emitted wavelength, which determines the colour of the light, as well as the active lasing medium. Currently, over 40 types of lasers have been developed with a wide range of both industrial and medical uses. Gas and solid-state lasers are frequently used in surgical applications, with CO_2 and Ar being the most common examples of gas lasers, and the Nd:YAG and KTP:YAG being the most common examples of solid-state lasers. At present, it appears that the CO_2, Nd:YAG, and KTP lasers provide alternative methods for achieving similar results, as opposed to superior results, when compared with traditional endoscopic techniques, such as cold-cutting monopolar and bipolar energy. This review focuses on the physics, tissue interaction, safety and applications of commonly used lasers in gynaecological surgery.

Keywords: Endoscopy, gynaecological surgery, laser, stimulated emission

History

The concept of stimulated emission was originally developed by Einstein, who described a phenomenon whereby light could liberate electrons from certain metal surfaces called the photoelectric effect (Einstein 1905). The principle of stimulated emission was first demonstrated experimentally in 1954, but for microwaves, and not light (Boznov and Perochorov 1954; Gordon et al. 1958). The theory was extended to the infrared and visible regions of the spectrum in 1958 (Schawlow and Townes 1958) and the first laser was constructed in 1960 (Maiman 1960). This early laser was constructed of a ruby crystal, surrounded by flash tubes, and emitted a red light, which was the result of chromium being present as an impurity in the crystal. Later that year, the Helium-Neon (HeNe) laser was developed, followed by the neodymium-doped yttrium-aluminum-garnet (Nd:YAG) laser in 1961 (Javen et al. 1961), the argon (Ar) laser in 1962 (Bennett et al. 1962) and the carbon dioxide (CO_2) laser in 1964 (Patel 1964). Currently, over 40 types of lasers have been developed with a wide range of both industrial and medical uses.

The CO_2 laser was first applied to gynaecological surgery in 1973 for cervical erosions, then for the treatment of cervical intraepithelial neoplasia (Bellina 1977) and microsurgery of the fallopian tube (Bellina 1983). The Ar laser was introduced clinically in 1983 for the treatment of endometriosis through the laparoscope (Keye and Dixon 1983), followed by the Nd:YAG laser in 1985 (Lomano 1985) and the KTP (potassium titanyl phosphate) laser in 1986 (Daniell 1986).

Physics

The term 'laser' is an acronym for Light Amplification by Stimulated Emission of Radiation. The laser beam is an electromagnetic radiation, similar to natural light, but is created by stimulated emission. The light that is generated is monochromatic and coherent, meaning that a single wavelength is emitted, and is spatially and temporally in phase (Figure 1). Lasers contain atoms or molecules, which can be simulated to higher energy levels by an external energy source. Specifically, the electrons are excited by this external energy source, and transfer to orbitals that are further away from the nucleus. The electrons in this energised state are unstable, and will spontaneously release energy in the form of an emitted photon when returning to their non-excited ground state. In any given laser, these photons will have a characteristic wavelength. When an emitted photon from one atom passes close to an identical excited atom, it can stimulate that atom to release a photon with the exact same characteristic wavelength. This is referred to as stimulated emission. Atoms in the ground state, however, can absorb photons. In thermal equilibrium, there are always more atoms in the ground state than in the excited state. In order to achieve a state in which there are more excited atoms than atoms in their ground state, termed population inversion, external energy must be supplied.

Lasers are commonly described by the emitted wavelength, which determines the colour of the light, as well as the active lasing medium. The active lasing medium can be a gas, a crystal or a liquid, and is housed in an optically resonant cavity, in which light of a specific wavelength resonates between two closed ends. At one end of the tube is a reflective mirror, and at the other end is a semi-transparent mirror. Some of the photons will be emitted along the axis of the optical cavity by chance, while others will be focused by mirrors to resonate along that axis. Those photons that are travelling along the axis will emerge from the semitransparent mirror in a parallel and coherent laser beam (Figure 2). The emerged photons could theoretically travel indefinitely in space as an unfocused beam, but in the case of lasers, they are focused through a lens or quartz fibre.

There are gas, solid-state, metal vapour, diode and free-electron lasers. Gas and solid-state lasers are those frequently used in surgical applications. The CO_2 and Ar lasers are examples of gas lasers, while the Nd:YAG and KTP:YAG are solid-state lasers. Copper and gold vapour lasers are examples of metal vapour lasers, and

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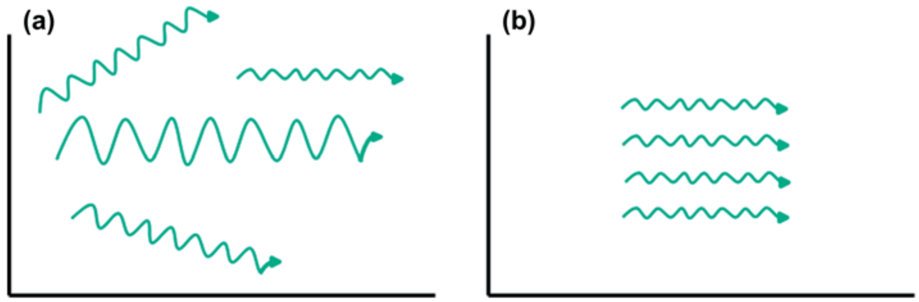

Figure 1. (a) Spatially and temporally out of phase beams are made up of photons that are travelling neither in parallel, nor have the same wavelength. (b) In contrast, spatially and temporally in phase beams are made up of photons that are travelling both in parallel, and have the same wavelength.

typically operate at low wattages. Gold vapour lasers have been used in photosensitiser-mediated photodynamic therapy (PDT) (Peng et al. 2008), which is described later in further detail. Diode lasers utilise semiconductors to fill in the gaps between anatomic energy levels. They can be used as excitation sources for other lasers, or in independent applications, such as percutaneous laser disk decompression (PLDD) for the treatment of thoracic disk disorders (Peng et al. 2008). Free-electron lasers utilise arrays of magnetic fields to force electrons to change directions, and thus emit radiation. Medical applications, such as the ablation of tissue, have been proposed, but the requirement of an electron particle accelerator makes it impractical (Peng et al. 2008).

Laser energy can be transmitted through the air using a hollow articulated arm with mirrors to bend the beam (Figure 3a) – or through quartz fibres optics. Whether or not a laser can be transmitted through a quartz fibre, depends upon how well the wavelength is absorbed by glass. If the wavelength is strongly absorbed by glass, it will not be efficiently transmitted. The thin, flexible, optical fibres are coated with an opaque nylon or metal casing (Figure 3b). They transmit visible and near infrared radiation by reflection off the casings. Lasers can also be transmitted by wave-guides, which are semi-flexible steel tubes, lined with ceramic tiles, whereby the beam bounces off of the tiles, and is mainly concentrated at the tip (Figure 3c). Recent advances in laser technology have led to the development of a flexible fibres delivery system for transmitting CO_2 laser energy. The flexible fibre is known as a photonic band-gap fibres assembly (PBFA), and consists of a hollow core, surrounded by a dielectric mirror, which is surrounded by outer cladding (Figure 3d). The dielectric mirror is composed of alternating layers of high and low refractive index material, which reflects light back into the hollow core.

Types of lasers

Over 40 different types of lasers have been developed, ranging from infrared to ultraviolet wavelengths with applications for military, industrial and medical use. Below, we describe common lasers used in gynaecological surgery.

CO_2

This is a gas laser, which emits a wavelength of 10,600 nm in the infrared portion of the spectrum. The radiation that is therefore produced is invisible. The lasing medium is actually a combination of helium (60–80%), nitrogen (~25%) and CO_2 (~5%), and the external energy source is usually either an electrical charge, such as from an electrical outlet, or a radio frequency field (Peng et al. 2008). It is considered to be the most versatile and safe medical laser, because of its limited depth of penetration. As soft tissue is 80% water, and the CO_2 laser is highly absorbed by water, deep penetration is prevented, as long as there is intra and extracellular water to be vaporised. Ultimately, the depth of penetration is determined by the water content of the target tissue (van Gemert and Welch 1989), but is generally limited to 0.1–0.5 mm, with a lateral thermal damage of 0.5 mm (DeLeon and Baggish 2008). Optical scattering occurs in tissues when wavelengths of less than 1,000 nm are used. Because of the long wavelength produced by CO_2 lasers, there is little optical scattering, which helps to minimise lateral thermal damage (Wang and Chocat 2010).

As described earlier, heat is delivered by the laser, and used to elevate the temperature of the target tissue. At temperatures over 100°C, vaporisation of the intracellular water occurs, with conversion of the cellular components to smoke. CO_2 lasers can be made to produce emissions of up to several kilowatts (kW),

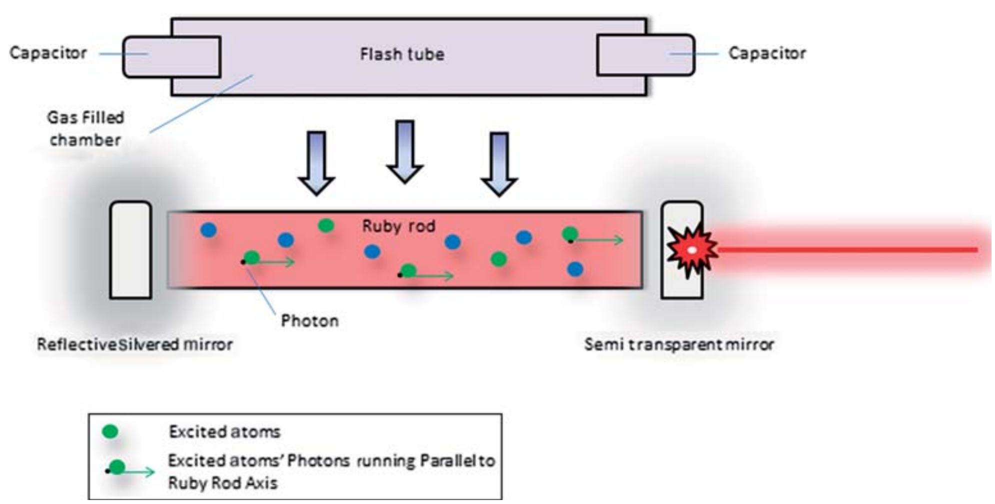

Figure 2. The photons that happen to be travelling along the axis will emerge from the semitransparent mirror in a parallel and coherent laser beam.

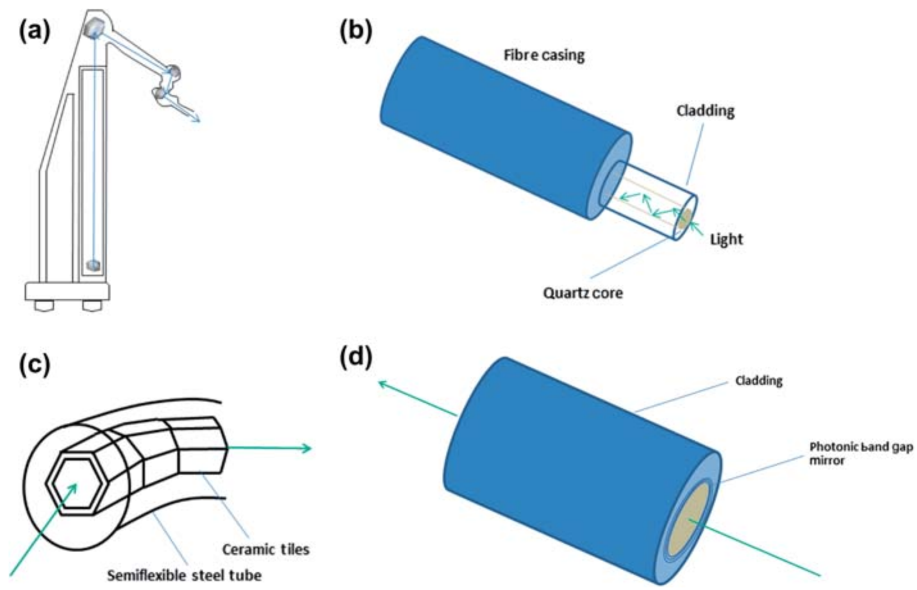

Figure 3. Laser energy can be transmitted by air, through a series of hollow articulated arms utilising mirrors (a); fibre optics (b); waveguides (c); and photonic band-gap fibre assemblies (PBFA) (d).

however, most medical applications only require 10–20 W. They are highly efficient, with 10–15% of input power converted to laser emission. High power densities have often been required to maximise vaporisation, and minimise tissue necrosis, which has led to the development of super-pulsed techniques. By pulsing the laser at extremely high rates, one can effectively slow down operating speed, while still maintaining high average power. This allows for precision, without compromising the cutting ability of the laser.

One of their major limitations has been the inability to transmit the radiation through optical fibres. Just as the wavelength is strongly absorbed by water, it is also strongly absorbed by glass. Previously, in order to deliver the laser beam to the abdomen for laparoscopic use, a rigid sleeve was required, as well as a lens with a long focal distance. By increasing the focal distance, one diminishes the ability to narrowly focus the beam, which decreases power density, and the ability of the laser to cut with minimal lateral thermal damage. Now, with the development of photonic band-gap fibres, the CO_2 laser can be easily adopted for endoscopic application. In fact, the flexible fibres can be coupled to conventional medical CO_2 lasers (Shurgalin and Anastassiou 2008). As is the case with traditional delivery systems, the beam can easily be defocused by changing the distance from the target tissue, allowing for cutting, ablation and coagulation.

Some of its other limitations include the inability to coagulate vessels > 1.0 mm, and its propensity to create both a plume and oxidised char. Once tissue has been charred, vaporisation of underlying structures is impeded (Bhatta et al. 1994). Additionally, CO_2 laser is absorbed by blood, limiting its effectiveness to dry surgical fields.

Nd:YAG

This is a solid-state laser, which uses a neodymium-doped yttrium aluminium garnet crystal. The Nd:YAG lasers had their earliest applications in military and defence, where they were commonly used as range finders, to determine the distance of an object, and designators, providing a target for laser-guided missiles and bombs. The external energy source for excitation can be a continuous or flashed Xe lamp, or a diode laser. It can operate in continuous or pulsed modes, and is capable of emitting at several wavelengths, of which 1,064 nm is the most frequently used. Like the CO_2 laser, the beam is invisible, and is often guided by a low energy laser, such as He:Ne. It can, however, be transmitted through quartz fibres, although there is divergence of the beam by 10–15°. The smallest spot size is obtained by using the fibres in contact with the target tissue. Because the wavelength is poorly absorbed by water, there is on average, a depth of penetration of 3–5 mm, with 3–5 mm of lateral thermal damage. To put this into perspective, there is an average of 1–3 mm of lateral thermal damage in the commonly used bipolar electrosurgical devices which utilise impedance feedback. There is an average of 2–6 mm lateral thermal damage when utilising non-impedance controlled bipolar devices. The dessication of tissue by any means can percolate steam through surrounding tissue, resulting in damage beyond what can be seen (Brill 2011). The power density of the Nd:YAG laser is thus greatest below the surface, with penetration 10–15 times greater than CO_2 laser (Barbot 1993). Additionally, there is scatter, which further contributes to thermal damage. As a result of the poor absorption by water, the depth of penetration, and the scatter, the interactive volume is increased relative to the size of the beam, diluting the power density, and decreasing the efficiency. The rise in tissue temperature is slower than that of CO_2 lasers, and rarely reaches 100°C (Barbot 1993). For this reason, the Nd:YAG laser is poor at vaporisation, but good at homeostasis.

The Nd:YAG crystal has other transitions, and the associated wavelengths can be amplified. One example is the 1,320 nm wavelength, which is absorbed by water to a greater extent. Increased absorption means increased efficiency and conversion of energy into heat. For the same penetration, the 1,320 nm wavelength requires less energy, allowing for shorter exposure time, and less thermal damage. Additionally, it has a lower scattering coefficient, which also contributes to a smaller interactive volume.

In order to improve cutting ability, sapphire tips were developed to focus the energy more efficiently (Daikuzono 1985). One drawback was that the tips needed to be cooled with a flow of gas or liquid. More recently, bare fibres have been modified to have moulded tips, in order to tailor the effect. An additional improvement is that the moulded fibres do not require cooling (Marlow 2008).

KTP:YAG

When a non-linear optical crystal is placed in front of the Nd:YAG laser beam, a second harmonic at half the wavelength (532 nm) can be generated (Figure 4). This is why the potassium titanium oxide phosphate (KTP) crystal is commonly referred to as a frequency doubling crystal. The KTP:YAG laser produces a blue-green light, the wavelength of which is strongly absorbed by reddish tissue containing haemoglobin or melanin. Conversely, the wavelength is not well absorbed by water or non-pigmented tissue. It has limited penetration in tissue, and can be transmitted by optical fibre. The depth of penetration ranges from 0.3 to 1 mm (Bhatta et al. 1994), and the spot size can be adjusted by transmitting through fibres of varying diameter (400–600 μm) (Marlow 2008). It is used for either homeostasis or vaporisation of pigmented tissue. It neither cuts or vaporises as well as the CO_2 laser, nor coagulates as well as a Nd:YAG laser. It is slightly more versatile than the previously mentioned lasers, and causes an intermediate amount of tissue damage.

Argon

This is a gas laser that emits outputs of predominantly 488 and 514.5 nm. Both of these wavelengths produce light in the blue-green portion of the spectrum. Like the KTP laser, the wavelengths are strongly absorbed by a variety of tissue chromophores, such as haemoglobin, and can be transmitted by fibreoptics. The argon laser is not as efficient as the KTP laser, however, and therefore a large amount of energy is lost as heat, necessitating a cooling system. It is used for its coagulative properties, and its ability to vaporise pigmented tissue, such as endometriosis.

He:Ne

This is also a gas laser that can be made to emit at various wavelengths, thus producing different coloured light. The 543 nm wavelength produces green light; the 594 nm wavelength produces yellow light; and the 633 nm wavelength produces red light. They produce an average output of only a few milliwatts (mW), and are mostly used for alignment or analytical purposes, such as an aiming beam for a non-visible laser.

Laser-tissue interaction

Laser-tissue interaction can result in a variety of effects, including photothermal, photochemical and photoacoustic. When a laser beam strikes the surface of a tissue, the photons can be absorbed, reflected or scattered. Absorption converts radiant energy into heat, while scattering results in a loss of power density, and can be associated with thermal damage due to elevation in temperatures below the boiling point.

Photothermal effects refer to the absorption of light, with the conversion of energy to heat. This is the most common application of laser energy in gynaecology. In contrast, surgical diathermy, also known as electrosurgery, is the production of heat caused by the passage of electrons through a material with resistance. The actual effect observed in tissue is dependant upon the amount of energy delivered, the wavelength of the laser, and the absorption coefficient of the tissue. The amount of energy delivered is a factor of wattage, time and beam spot-size. Power density is described as Watts/cm^2, and is therefore inversely proportional to the area of the spot-size. In each tissue, the absorption coefficient is specific to a given wavelength. Photons with wavelengths in the far infrared range are highly absorbed by water, whereas wavelengths in the visible and near-visible regions of the spectrum are absorbed by chromophores, such as haemoglobin and melanin. The higher the absorption coefficient, the lower the depth of penetration in a given tissue. The combination of high absorption and low scatter allows for a small interactive volume, thus a high power density, and a resultant rapid rise in temperature.

At temperatures below 57°C, reversible damage occurs. It is at these relatively low temperatures that tissue welding is possible. The heating of tissue causes uncoiling of proteins and annealing of collagen, whereby opposing tissue edges can be fused (Bhatta et al. 1994). At temperatures between 57°C and 100°C, irreversible damage occurs as a result of denaturation of proteins, and cell death ensues (Marlow 2008). While this effect is responsible for haemostasis, it is also responsible for necrosis. Once the temperature has risen to 100°C, boiling of water occurs, which results in vaporisation of cells with high water content. The exact temperature required for vaporisation depends upon the tissue, with calcified plaques, for example, requiring a temperature upwards of 500–1,000°C (Bhatta et al. 1994). For most tissues encountered in colposcopic and endoscopic procedures, however, vaporisation occurs at 100°C. At 100°C and above, vaporisation occurs as long as there is water present. Following desiccation, carbonisation occurs (Bhatta et al. 1994). Carbon residues continue to absorb heat, and may unnecessarily raise tissue temperatures, resulting in irreversible damage and necrosis (Barbot 1993).

Particularly with lasers transmitted through the air, the energy distribution is not uniform throughout the cross-section of the beam, with the highest power density concentrated in the centre. With fibreoptic lasers, the energy distribution tends to be more uniform, but beam divergence occurs at the tip, such that the greatest concentration of energy is at the fibre-air or fibre-tissue interface. Because the energy distribution is not uniform, the impact of a laser beam on tissue creates a crater, with three distinct zones of injury. The zone of vaporisation is marked by the V-shaped defect, or absence of tissue. Below this, lies the zone

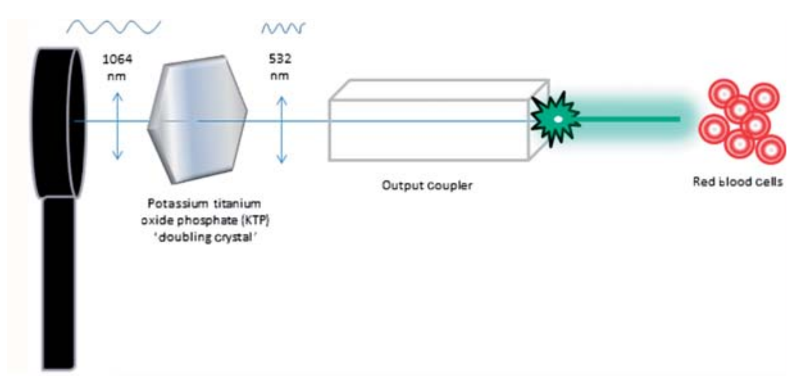

Figure 4. When a non-linear optical crystal, referred to as a frequency-doubling crystal, is placed in front of the Nd:YAG laser beam, a second harmonic at half the wavelength can be generated.

of necrosis, where small vessels (< 1 mm) are sealed (DeLeon and Baggish 2008). The deepest zone is that of reversible thermal damage (Figure 5). Additionally, any areas of char are at risk of inducing further damage, as the diffusion of heat can contribute to the damage of lateral tissues.

Beyond the area of vaporisation, on the periphery of the interactive volume, heat is dissipated by blood perfusion (Barbot 1993). Cooling efficiency differs by tissue type, based on the perfusion time (Peng et al. 2008). The perfusion time of the cortex of the kidney, for example, is 20 seconds, while that of adipose tissue is 4,000–5,000 seconds (Svaasand 1989). If more energy is deposited in a volume than can be removed by blood perfusion, the temperature of the tissue will rise (Peng et al. 2008). Selective heating of a high absorbing region can be obtained by pulsing a laser, such that the pulse duration is less than the thermal diffusion time across the target region. Essentially, the tissue is allowed to cool between pulses. This is termed thermal relaxation, or conductive cooling. The pulse duration is thus chosen to be long enough to allow heat to diffuse into a target, but small enough to prevent the rise in temperature of the surrounding tissue. Typical pulse durations are 0.5–10 ms (Peng et al. 2008). When lasers are pulsed, they can be used at higher power settings, with resultant higher power densities. Tissues can thus be cut, with minimal coagulative necrosis. Using pulsed high power densities also allows for cutting tissue with lower water content, which require higher temperatures for vaporisation.

Vaporisation and tissue ablation can require temperatures ranging from 100–300°C. To avoid carbonisation or charring, which occurs at temperatures exceeding 300°C, a narrow temperature range must be maintained. As mentioned earlier, pulsing of high power-density lasers can allow for the maintenance of temperatures within a given range, without the need to operate quickly, as would be required of a continuous high power-density laser. Another practical application for the use of a pulsed laser might be a highly calcified myoma, which would otherwise be extremely time consuming to ablate with a continuous low wattage laser. One caveat, however, would be the potential for encountering areas of necrosis, which would have much higher water content. Care must thus be taken when performing myolysis, to avoid injury beyond the target myoma when using pulsed high power-density lasers.

Photomechanical, or photoacoustic, effects occur with rapid heating of a tissue, and requires nanosecond or shorter pulses with extremely high energy densities. During rapid heating, steam formation causes expansion, resulting in a mechanical shockwave. These mechanical shockwaves, which travel at supersonic velocities, can cause mechanical rupture, such as in lithotripsy (Peng et al. 2008).

Photochemical effects occur when absorbed energy causes the excitation and rearrangement of molecular bonds. One application of this would be the use of a photosensitising agent, which is light activated and lesion localising. The laser energy is absorbed by the sensitising agent, which is a photoactivatable chemical, causing the generation of reactive oxygen species and free radicals by transferring energy to molecular oxygen. Amongst reactive oxygen species, singlet oxygen is thought to be the most cytotoxic (Devasagayam and Kumat 2002). This is termed photooxygenation, and causes the destruction of tissues containing the photosensitizer. Red light with a wavelength of 630 nm is commonly used (Moan et al. 1998), and does not generate thermal changes in the target tissue.

Safety

The most commonly injured organs by misdirected laser beams are the skin and the eye. The eye is particularly vulnerable because it lacks a protective layer of pigmented cells, by which energy could be absorbed. Additionally, the ocular lens can focus the incident beam on the retina, creating a very small spot size, and a high resultant power density (Peng et al. 2008). The laser beam irradiance on the retina can be multiplied by a factor of 10,000 when compared with the cornea, such that low powered lasers can burn holes in the retina, while sparing the cornea and other structures of the eye (Gabay 2003). This effect is limited to lasers in the visible spectrum, as they are not absorbed by the watery structures in front of the retina. This is in contrast to the ophthalmological applications of lasers, which are effective precisely because they

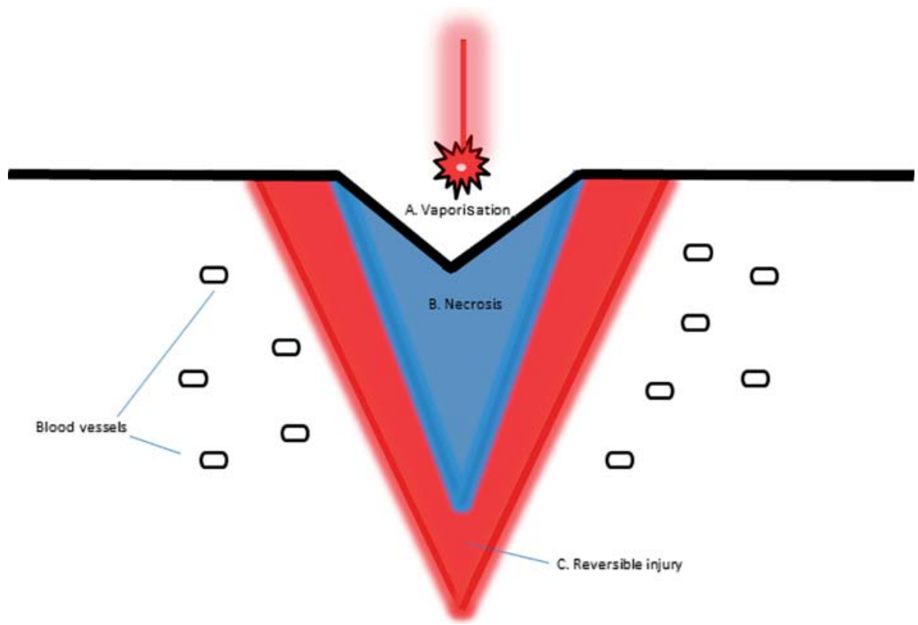

Figure 5. The impact of a laser beam on tissue creates a crater, with three distinct zones of injury. The zone of vaporisation is marked by the V-shaped defect. Below this, lies the zone of necrosis, where small vessels are sealed. Finally, the deepest zone is that of reversible thermal damage.

can enter the eye without causing injury to the structures anteriorly. Ophthalmological applications include the treatment of glaucoma, diabetic retinopathy, macular degeneration and the correction of vision (Peng et al. 2008). The use of laser in eye surgery, however, is quite precise, unlike stray beams. Safety goggles are therefore particularly important, as the blink reflex of the eye is not fast enough to prevent damage to the retina, and are specific to individual lasers. Prescription glasses are considered adequate protection when using CO_2 lasers however, due to the absorption of the wavelength by glass. Windows and doors should be covered, and a sign should clearly be displayed prior to entering the OR, stating that a laser is in use.

Although an important part of all laser safety, use of the 'stand-by' mode is particularly important when using a laser for extraperitoneal surgery. In such instances, use of fire-retardant or wet drapes can also minimise injury to the patient from stray beams.

Stray beams are not only generated by improper use or failure to institute proper safety measures, they can result from breakage of transmission fibres. Laser energy will be delivered at the point of breakage of optical fibres, and can cause injury to the patient or staff, depending upon the location of the breakage.

During photovaporisation, the laser plume is known to contain hazardous air-borne contaminants, necessitating the use of suction and a local exhaust ventilation system. These contaminants range from toxic by-products and carcinogens (Baggish and Elbakry 1987) to intact viral DNA (Garden et al. 1988; Ferenczy et al. 1990).

Prior to using a laser beam clinically, surgeons should undergo proper laser training. Each laser manufacturer has its own training procedures, and surgeons should be advised that training is required for each device, regardless of if it utilises a wavelength similar to a device with which they are familiar. This is important, as the safety requirements and procedures can differ.

Applications

While the advantages of using laser technology for the treatment of CIN, VIN, VAIN and condylomatous disease have been well documented over the years (Baggish 1980; Baggish and Dorsey 1981; Baggish 1982; Townsend et al. 1982), it is unclear if the endoscopic applications are actually superior to alternative techniques. At present, it would appear that the CO_2, Nd:YAG, and KTP lasers provide alternative methods for achieving similar results, as opposed to superior results, when compared with traditional techniques.

Laser vaporisation is well suited for the treatment of superficial endometriosis. While the argon and KTP lasers are well suited based upon their absorption by pigmented lesions (Keye and Dixon 1983), the limited depth of penetration and peripheral thermal damage of the CO_2 laser allows for treatment of disease over delicate structures, such as the ureter, bladder and bowel. Additionally, lesions with greater depths of invasion can be resected, and endometriomas can be excised (Sutton and Jones 2002). The ability to defocus the laser, contributes to its versatility, and allows for cutting, ablation and coagulation, all without the need to exchange instruments. The ease of achieving the desired surgical outcome with respect to endometriosis is certainly evident, but there appears to be no advantage in pregnancy rates (Lotz and Grunert 1989). Similarly, the use of the laser in adhesiolysis (Luciano et al. 1992) and treatment of ectopic pregnancy (Paulson 1992) has not yielded superior results when compared with cold endoscopic instruments and electrosurgery. Neither superior treatment, prevention of adhesions (Barbot et al. 1987), nor improved pregnancy rates after laser adhesiolysis have been demonstrated (Tulandi 1986).

The use of laser energy for the laparoscopic treatment of pedunculated and subserosal fibroids does have some advantages over electrosurgery, related to the decreased volume of destruction of normal myometrium. The decrease in thermal damage associated with laser myomectomy does appear to be associated with a favourable decrease in adhesion formation. Additionally, there appears to be an improvement in haemostasis, with the trade-off being slightly longer operative times (Luciano 1992). When the depth of penetration is limited to several millimetres, enucleation of larger myomas, and vaporisation of smaller myomas, may prove time consuming.

There are a variety of hysteroscopic applications, including endometrial ablation, resection of myomas and polyps, septoplasty and lysis of intrauterine synechiae. The use of laser energy for the treatment of menorrhagia was first reported in 1981 by Goldrath et al. (1981). This early endometrial ablation utilised a Nd:YAG laser, which could be used with standard hysteroscopic distension media, unlike CO_2. Both contact and non-contact techniques have been described, with the contact technique yielding a 4–6 mm depth of ablation at 40–50 W, and amenorrhoea rates ranging from 49% to 54% (Lomano 1991). This could be quite time-consuming, as the entire surface of the endometrial cavity needed to be systematically ablated. With the advent of the rollerball electrode and global ablative techniques, laser ablation has largely been replaced by simpler and less expensive alternatives. As previously mentioned, the Nd:YAG laser can also be employed for resection of uterine septum, with improved haemostasis over cold scissor techniques. At one point, septoplasty and other intrauterine procedures were performed with a Nd:YAG laser and a sapphire tip, however, the CO_2 gas required for cooling was thought to be responsible for several emboli-related deaths (Baggish and Daniell 1989).

Advancements in applied laser technology

Omniguide®'s Beampath™ fibre system solves the problem of older 'line-of-sight' CO_2 gas systems with lack of flexibility in the laser path. It transmits CO_2 laser energy using a photonic bandgap fibre mirror lining around a hollow core (see above). The combination of the flexible fibre system and its handheld tip allow the surgeon easier access to difficult to reach anatomical regions. Some of its first applications were in otolaryngology. It has been adapted for use with the Da Vinci robot.

The Beampath™ fibre system is well suited for endoscopic procedures as it can fit through both rigid and flexible endoscopes and comes with multiple handpieces. The fibre itself is thin and can be inserted through as small as 3 mm laparoscopic trocars. It has also found a use in robotic surgery such as myomectomy. It is secured to a robotic instrument (i.e. needle driver) by a notch at the tip of the fibre.

LISA Laser's Revolix™ is a 2 µm continuous wave holmium-YAG laser. Its advantages include a fibre that can be reused up to 20 times. It also can be used in flexible and rigid endoscopes as well as various handpieces. Intuitive Surgical Inc. has designed a RevoLix-specific 5 mm introducer to be used with the da Vinci robot. The flexibility of the robotic motions allows access to difficult to reach regions.

Conclusions

There are over 40 different types of lasers, with applications in military, industrial and medical use. Gas and solid-state lasers are most frequently used in surgery, specifically, CO_2, Ar, Nd:YAG, and KTP:YAG . CO_2 laser is considered to be the most versatile and safe, and now with the development of photonic band-gap fibres, are easily delivered for endoscopic use. At present, laser technology provides alternative methods for treating adhesive disease and endometriosis, as well as serving as a cutting and coagulating instrument with minimal destruction of adjacent tissues.

The proper use of a laser is dynamic, and the effects are dependant upon the static and non-static characteristics of the surgical field. It is important to not only understand the depth of penetration of a given wavelength in tissues of varying water content, but how these effect are altered by desiccation or a bloody surgical field. Similarly, it is important to understand why certain wavelengths are ineffective on given tissues, or require higher powers. Damage to surrounding structures due to lateral thermal spread and charring can result in delayed injury, requiring one to be cognisant of anatomical relationships. By having an understanding of the physics and tissue interactions of commonly used lasers, one can select a laser with appropriate characteristics for a given task, anticipate complications, troubleshoot and avoid injuries.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Bruce S. Kahn, MD is a paid consultant for OmniGuide® CO_2 laser.

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