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RESEARCH ARTICLE

LASERS IN OPHTHALMOLOGY

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Abstract

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This article reviews the principle uses of ophthalmic lasers, providing historical background with an emphasis on new applications and areas of investigation. Ophthalmic photocoagulation was the first medical laser application and has restored or maintained vision in millions of people. The use of ophthalmic lasers is becoming increasingly widespread, with most eye departments now having at least one type of laser. Many patients are treated withlasers and many more request such treatment, even when it is not indicated. The indications for ophthalmic lasers are constantly changing as experience with established treatments increases and new equipment is developed.

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Introduction:-

Since its development almost 60 years ago, lasers have made a huge impact on the medical field. The laser came about after the attempts by Charles Towns and Arthur Schawlow to produce a maser (microwave amplification by stimulated emission of radiation) that had higher frequency coherent radiation at wavelengths in the visible spectrum.[1]

The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation and is the realisation of a concept postulated by Einstein in 1917 in the course of a theoretical investigation of blackbody radiation.[2]

Since its invention half a century ago, laser has made possible a large number of applications in a wide range of fields: industry, science, medicine and more.[3]Meyer Schwickerath first described clinical retinalphotocoagulation in 1949. He initially used focusedsunlight to produce chorioretinal scars in treatingretinal holes.[4]Ophthalmologists have been at the forefront of developing medical uses for new laser technology since the report of the first laser in 1960.[5]

Ophthalmology was the first medical specialty to utilize lasers, with the first report utilizing a ruby laser to treat ocular lesions almost a year after the invention of the laser, and still has the most laser procedures compared to any other specialty with the use of lasers permeating all subspecialties both diagnostically and therapeutically.[6]

Lasers can be defined by their medium, which can be gas (including argon and argon fluoride), liquid (including dye), solid (including neodymium: yttrium-aluminum-garnet), or semiconductor (diode).[7]

Lasers have become as essential to the practicing ophthalmologist as the scalpel, the magnifier and sterile gloves. Therefore, understanding the principles of lasers is integral to the foundational knowledge of ophthalmologists. In

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this review article, we will discuss the principles of lasers, the different types of lasers in ophthalmology, their therapeutic and diagnostic uses in ophthalmology.

Lasers

Laser is an acronym for light amplification by the stimulated emission of radiation. Emission of radiation is stimulated by elevating electrons in a suitable gas or solid material into "high energy states" with an electric current or light of an appropriate wavelength. When a high energy electron is struck by a photon of the correct wavelength it emits two photons. These two photons (the stimulated emission) are of identical phase, direction, and wavelength. The laser energy is amplified and focused into a delivery system that incorporates devices to protect the user and others present in the laser suite.[4]

Principles of laser

Light emission light is composed of individual packets of energy called photons. For stimulated emission to occur more frequently than absorption and hence result in light amplification, the optical material should have more photons in an excited state than in a lower state. Such ‘‘population inversion’’ can be achieved using an excitation source, or ‘‘pump,’’ such as a flash lamp or electrical source that imparts the energy to achieve population inversion into the cavity. In that cavity, emitted light circulates between 2 mirrors on either side, with a fraction of the photons escaping through an aperture in 1 of the 2 mirrors, which is semi-reflective, to form the laser beam. The light trapped inside the cavity stimulates emission of new photons from the excited laser material with the same wavelength, direction, and phase, thereby forming a coherent laser beam. This beam can then be directly emitted into space, focused with an appropriate lens system, transmitted by a fiber-optic cable or some combination of the above to achieve the desired effects.[1]

Laser–tissue interactions

Interactions of light with biological tissues depend on its wavelength, pulse duration, and irradiance (amount of power per unit area, W/cm^2). With sufficiently high photon energy, light can induce photochemical reactions. Light absorption by the tissue can also result in heating, which may lead to thermal denaturation. At higher temperatures, and especially with shorter pulses, tissue can be rapidly vaporized, which can result in mechanical disruption or tissue ejection. Very short pulses with high peak irradiance can ionize materials, enabling precise dissection of tissue. These types of interactions are described below in more detail.[6]

Mechanisms of Lasers

The mechanisms of lasers can be separated into three types based on the power density of the laser and its exposure time with the tissue. The categories are (in ascending order of power density) as follows:[1]

1. Photochemical interaction
2. Thermal interaction
3. Photodisruption

Photochemical:

Light-induced chemical reactions are typically not associated with a meaningful change in tissue temperature.[1] Photochemical interaction are the basis for retinal photodynamic therapy in age-related macular degeneration, or cross-linking of corneal collagen with riboflavin to treat keratoconus.25 To avoid heating, therapeutic photochemical interactions are typically performed at very low irradiances ($<1W/cm^2$) and with long exposur-10second or minutes.[8]

This includes:

1. **Photodynamic:** here a photosensitizing agent is injected intravenously to be taken up by target tissue. Thereafter the target tissue is exposed to red laser light. This generates cytotoxic free radicals and thus the desired laser effects. photodynamic therapy for the treatment of proliferating vascular disorders of the cornea and retina, the treatment of infections and the treatment of proliferative lens epithelium following cataract surgery.[9]
2. **Photoablation:**A new form of laser-tissue interaction was discovered in 1983 by Trokel and Srinivasan working at IBM. Photoablation occurs because the cornea has an extremely high absorption coefficient at 193 nm, and the photons at 193 nm are highly energetic, possessing more energy than the carbon-carbon bonds interlinking the protein molecules of the cornea.[9]

Photothermal:
Photothermal laser-tissue interactions occur when laser energy is absorbed by the target tissue and convertedinto heat. The effect upon the tissue depends on both the magnitude and rate of temperature elevation.[9]Depending on thetemperature rise and duration of exposure, different tissueeffects may occur, including metabolic alterations, necrosis,and vaporization.The absorption coefficient of biologictissue chromophores strongly depends on the laserwavelength.[1]

Photodisruption (photoionizing):
Here laser is applied to the target tissue. The laser strips electrons from the target tissue. This creates a shock wave that disrupts the target tissue. Eg: ND: YAG laser.

Laser delivery systems:
Following are the techniques for delivering laser to the target tissues in ophthalmology:

1. **Slit-lamp:** This is a common mode of delivery of laser to the target tissue where the power, spot size, etc can be easily modulated.A new, navigated laser approach is recently gaining favor by providing the physician with real-time visibility and treatment control. The Navilas photocoagulation system is a unique technology that combines color fundus photography, FA, and IR imaging with a target locked frequency-doubled solid-state laser (wavelength 532 nm). Navilas is a fundus camera-based laser system as opposed to the conventional slit lamp-based laser systems.[10]
2. **Indirect ophthalmoscope:** It is a fiber optic cable delivers diode or argon laser to the retina. Spot size depends on the diopteric power of the condensing lens used. It is a useful technique to allow a wide angle view of the fundus, to screen for retinal disease, and to examine the peripheral retina.[11]
3. **Endophotocoagulation:** this system was developed for transvitreal application of photocoagulation using a fiberoptic probe. It is used at the time of surgery via pars planar route as in vitrectomies or treatment of proliferative diabetic retinopathy. A fiber optical cable delivers argon green or diode laser.[12]

Lasers can be defined by their medium, which can be gas (including argon and argon fluoride), liquid (including dye), solid (including neodymium: yttrium-aluminum-garnet), or semiconductor (diode).[7]
The main types of laser energy and their uses are listed below:

Solid state: 1. Ruby
2.Nd:YAG
Gas: 1. Argon
2.Krypton
3. Carbon dioxide
Dye: Dye laser
Diode: 1. Gallium-Aluminium-Arsenide
Excimer: 1. Argon Fluoride
2. Krypton-Fluoride

Argon and krypton lasers.
Intraocular applications require the transmission of radiation, which occurs to different extents between - 380 and 1,400 nm. In this range, important chromophores are melanin, in the retinal pigment epithelium (RPE) and iris pigment epithelium, uvea, and trabecular meshwork, hemoglobin in blood vessels, and xanthophyll in the inner and outer plexiform layers in the macula, as well as in certain cataracts.[5]

Argon green is strongly absorbed by haemoglobin and hence may be used to treat vascular abnormalities. It may also damage normal retinal blood vessels.

Krypton red and diode infrared laser wavelengths, on the other hand, are not strongly absorbed by haemoglobin and do not occlude large vessels. These wavelengths are useful when peripheral retinal photocoagulation is performed in the presence of vitreous haemorrhage.

Argon blue is absorbed by macular xanthophyll and may cause damage to the inner retina. Green, red, and infrared wavelengths are used for treating macular lesions as they do not damage macular xanthophyll.[4]

Nd:YAG:
The Nd:YAG laserhas a photocoagulation or photodisruption effect.[13]Thislaser of radiation at 1,064 nm is much less absorbed by melanin than is visible light, so that it penetrates much deeper than the output of other photocoagulation lasers. Nd:YAG lasers can be configured so that their output is continuous or long-pulsed (up to **20** ms), with predominantly thermal effects.[5]

Tunable dye laser:
Dye lasers, themselves pumped by other lasers, employ one or more dyes to produce emissions over a wide range of wavelengths. Tunable dye lasers allow the operator to select the desired wavelength within the range of the dye in use. This offers at least the theoretical potential for perfect matching of laser output with tissue absorption.[5]

Diode laser:
When diode lasers were first introduced, they were composed of semiconductor crystals of gallium arsenide (GaA) doped with aluminium.[14] When this is excited by an electrical current it emits infrared energy as a laser beam of wavelength between 790- 950 nm with a peak at 810 nm. They are compact and require no cooling facilities. They are cheap and require no laser tubes.[15]

Excmiers:
Excimers, **or** excited dimers, are molecules with bound upper states and weakly bound ground states.The best performance has been demonstrated by excimers formed by the reaction of an excited rare gas atom with a halogen molecule, in which the rare gas atom acts as the corresponding alkali metal and becomes very reactive in the presence of halogen-containing molecules.[5]The excimer laser has been the most commonly used laser for corneal applications. Although this has primarily been refractive surgery, phototherapeutic keratectomy with the excimer laser has been used for corneal disorders involving the epithelium or anterior stroma, including recurrent erosion syndrome, corneal dystrophies, keratopathies, scars, and pterygia.[13]

Uses of LASER in Ophthalmology:
Lasers in ophthalmology have a diagnostic and therapeutic role. The flow chart below gives a brief summary of the uses of laser in ophthalmology.

A)Diagnostic uses: [9]
The high radiance, monochromaticity, and spatial and temporal coherence make the laser a unique light probe for noninvasive diagnostic applications in ophthalmology. The information contained in laser light reflected or scattered by intraocular structures can be detected and analyzed for diagnostic purposes.

i) laser technology has been utilized in investigation techniques such as Confocal scanning laser ophthalmoscope (CSLO), which is used for optic nerve head evaluation, Optical coherence tomography (OCT), which is useful in the evaluation of retinal pathology, corneal pathologies, etc.
ii) Laser retinal Doppler flowmetry is useful in evaluating the optic nerve head perfusion. Also in this laser light scattered by moving blood cells is shifted in frequency and is used to measure the rate of blood flow in the veins and arteries of the retina.
iii) Visual Acuity Measurement is the spatial coherence of lasers is used to form interference fringes on the retina. These are dark lines with variable spacing and orientation whose formation is largely insensitive to the optical clarity of the intervening media.

B) Therapeutic uses:
Cornea:
Lasers have been utilized in procedures for refractive error correction like LASIK, epi-LASIK, LASEK, PRK, and therapeutic procedures such as phototherapeutic keratectomy (PTK) for the removal of surface irregularities, small corneal opacities.[16]

Glaucoma:
A wide variety of laser procedures with different indications are performed in glaucoma. Of these, the most common procedure is Neodymium: Yttrium–Aluminum Garnet Laser Peripheral Iridotomy (Nd:Yag LPI) done in angle closure category. Laser trabeculoplasty (LTP) yet another procedure though in use since 1979 has regained interest due to recent developments in this technique like selective laser trabeculoplasty (SLT) increasing its safety profile and hence widening applicability. Other laser procedures currently being used include gonioplasty/iridoplasty, diode laser cyclophotocoagulation (DLCP), endocyclophotocoagulation (ECP), laser suturolysis, bleb remodeling,

iridolenticular synechiolysis, Nd:YAG laser hyaloidotomy and goniopuncture and excimer laser trabeculotomy (ELT).[17]

Cataract:
Femto laser-assisted cataract surgeries (FLACS)include precise circular capsulotomy formation, lens fragmentation, lens softening and post-cataract surgery for removal of capsular opacification as in Nd: YAG posterior capsulotomy.[18]

Retinal neovascular diseases:
Laser treatment for diabetic retinopathy was the first intraocular treatment to provide a highly effective means for preventing visual loss in patients with diabetes.[19]The aim of laser treatment in these cases is to eliminate hypoxia retina so as to eliminate the stimulus for neovascularization. This is called **Pan retinal photocoagulation.**Panretinal coagulation is a procedure involving placement of laser burns in the peripheral retina, the thermal energy from which induces tissue coagulation Argon or Krypton laser may be used for the same.[20]

Retinal tears and retinal detachment:
Retinal tears and small retinal detachments may be treated with Focal laser photocoagulation. Therapeutic laser photocoagulation was recommended for detachment confineto necrotic areas, minimal detachment of normal retina, or peripheral detachments in which laser photocoagulation could be applied to completely surround the detachment and necrotic retina.[21]

Choroidal neovascular diseases:
Laser photocoagulation can reduce the risk of severe visual loss in patients with well-defined choroidal neovascular membranes (NVMs) that do not involve the center of the fovea. Inner retinal absorption of argon energy may have contributed to the development of retinal revascularization. Use of krypton red or dye red wavelengths might reduce the frequency of revascularization.[22]

Intraocular tumors:
Lasers have been employed in the management of intraocular tumors. Tumors like Retinoblastomas, melanomas, and retinal angiomas can be treated with focal Argon or Krypton lasers.[23]

Diabetic macular edema:
The role of argon laser photocoagulation in treating different types of diabetic maculopathy.[24]

Summary and Conclusion:-
During the past two decades, laser technology has revolutionized many aspects of ophthalmic surgery. Millions of patients have benefitted from the restoration or preservation of vision from laser treatment. The use of lasers to successfully treat retinal diseases, glaucoma, and capsular opacification following cataract surgery is now the standard of care. The end result of the interactions between basic scientists, clinicians, and industry that have produced this revolution has markedly improved in the ability of ophthalmologists to help their patients.

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Conflicts of interest:
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