Regular Review

Current uses of ophthalmic lasers

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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 with lasers 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. This article provides a summary of current uses of ophthalmic lasers as well as examples of recent developments.

Meyer Schwickerath first described clinical retinal photocoagulation in 1949. He initially used focused sunlight to produce chorioretinal scars in treating retinal holes. Sunlight, the availability of which was at the mercy of the weather, was superseded by the xenon arc lamp as an energy source, and later ruby and argon blue-green laser photocoagulation was developed.¹ Commercially available lasers developed specifically for ophthalmic use have been available since the mid-1960s.²

Principle of 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.

The interaction between the laser beam and tissues consists of four components. These are, in sequence, laser transmission, absorption, degradation, and the tissue reaction.²

The transparency of the ocular media lends itself to the transmission of laser light in the visible and near infrared spectrum. Ocular absorption is related to the laser wavelength and the type of pigment in the target tissue. The main absorbing ocular pigment is melanin, which is present mainly in the retinal pigment epithelium, iris pigment epithelium, and the trabecular meshwork. Argon, krypton, dye, and diode laser wavelengths are all absorbed by melanin. Other absorptive pigments found in the eye include xanthophyll, which is found in the retina at the macula, and the light absorbing pigments found in the rod and cone photoreceptor cells.

The main types of laser energy and their uses are listed below.

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.

Diode and neodymium YAG (yttrium-aluminium-garnet) lasers produce invisible infrared wavelengths which readily pass through the sclera as well as the cornea, aqueous, lens and vitreous. These lasers can therefore be used to treat intraocular structures by using a beam which passes through either the cornea or the sclera.

Laser energy can cause several types of degradation in targeted tissue. These include photocoagulation, photodisruption, and photoablation.

Photocoagulation

Photocoagulation is a thermal process in which laser radiation is absorbed by the target tissue and converted into heat, resulting in thermal denaturation of proteins. Argon, krypton, and tuneable dye lasers all work on this principle, as do the more recently introduced continuous wave YAG and diode lasers. Photocoagulation is used for treating proliferative retinopathy, diabetic maculopathy, macular degeneration, retinal holes, and chronic open angle glaucoma.

NEOVASCULAR PRERETINAL PROLIFERATIVE RETINOPATHY

In neovascular preretinal proliferative retinopathy new vessels grow from the retina into the posterior vitreous face (fig 1). Two serious consequences of retinal neovascularisation are vitreous haemorrhages and traction retinal detachment. Formerly this condition often led to complete blindness.³ It is most commonly due to diabetes or occlusion of retinal veins.

Research has established that new vessels of the retina or optic disc in diabetes are found in eyes with extensive retinal ischaemia,⁴ and that these new vessels regress only after extensive photocoagulation of the retinal pigment layer and outer retina. Direct ablation of the new vessels alone is insufficient to prevent the proliferation of further new vessels. Figure 2 shows retinal burns after panretinal photocoagulation.

The reason why panretinal photocoagulation works is not clear, but studies have shown that it halves the incidence of severe visual loss over two years in patients

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with vitreous haemorrhage and severe proliferative neovascular diabetic retinopathy.⁵ Ischaemic neovascularisation of the anterior segment causing painful rubeotic glaucoma often accompanies extensive retinal ischaemia. This can be prevented and ameliorated by peripheral retinal photocoagulation.

The procedure can be uncomfortable but is generally painless. The patient sits at a slit lamp and the ophthalmologist uses a specialised contact lens to scatter the laser burns over the peripheral retina, scrupulously avoiding the macula and optic disc. Patients may lose some peripheral and night vision if they have had extensive peripheral panretinal photocoagulation. In general, however, there is surprisingly little effect on visual function.

DIABETIC MACULOPATHY

Diabetic retinopathy is the commonest cause of blindness in people of working age in Britain.^{6,7} Diabetes may cause proliferative retinal vascular disease or diabetic maculopathy. Diabetic maculopathy is even more common than proliferative diabetic retinopathy and tends to affect those with adult onset diabetes, many of whom have maculopathy at the time of diagnosis of hyperglycaemia. Dysfunction of the macular capillary endothelium secondary to diabetes allows fluid and lipid to leave the capillaries and enter the inner retina and impair central vision. Treatment with laser burns to the leaking areas or in a grid over the macula can be successful in "drying" the retina,

FIG 1—Fluorescein angiogram of new vessels of optic disc showing (top) vascular leakage prior to treatment and (bottom) regressed vessels with no leakage after panretinal coagulation

FIG 2—Fundus photograph showing fresh retinal burns after panretinal photocoagulation

stopping the deterioration of vision or even producing improvement (fig 3). The treatment has to be more precise than panretinal photocoagulation as the burns are placed much closer to the fovea.

MACULAR DEGENERATION

Age related macular degeneration is now the commonest cause of registerable blindness in the United Kingdom.^{6,8} In most patients it consists of atrophy of the posterior pole with loss of central vision but maintenance of peripheral vision. Its cause is unknown and it cannot be cured by laser treatment. In some patients, however, new blood vessels arising from the choroid proliferate underneath the retina. These vessels usually begin outside the fovea but grow very rapidly. Ultimately the new vessels form a "disciform scar," which usually severely reduces vision.

If these vessels begin outside the so called "foveal avascular zone" (a 500 μ m ring centred on the fovea) and the patient presents before the foveal avascular zone becomes affected the new vessels can be obliterated by photocoagulation. This will produce a scotoma, which since it is close to the centre of vision can be a nuisance, but central vision is preserved.

The prospects for retaining central vision are worse when the subretinal neovascular membranes lie beneath the foveal avascular zone. Research into the definitive laser management of neovascular membranes in this zone is continuing. Recent studies show that laser ablation of subfoveal neovascular membranes offers a better visual prognosis than no treatment.^{9,10}

Patients with subretinal neovascular membranes present with distortion of central vision and decreased visual acuity. Patients with these symptoms must be referred urgently for specialist ophthalmic assessment because the visual prognosis is related to the site and size of the membrane at presentation. Even if successfully treated by laser there is a high recurrence rate of between 16% and 59%.^{11,12}

RETINAL HOLES

Retinal holes can allow fluid from the vitreous to track through the retina and into the subretinal space. This can produce retinal detachment and consequent blindness in some patients. Holes can persist for a long time before this happens, and if they are discovered before detachment they can be surrounded by laser burns. The resultant scarring attaches the retina adjacent to the hole to the underlying tissues, welding the retina down and preventing fluid tracking through the hole and under healthy retina (fig 4). Because most holes are very peripheral the laser burns do not affect vision. If the retina has detached laser therapy is not useful. Surgery is required to close the retinal hole and drain away the subretinal fluid. Once the retina has

been surgically reattached laser treatment can be used to prevent it detaching again.

CHRONIC OPEN ANGLE GLAUCOMA

Glaucoma is used to describe several conditions in which there is raised pressure inside the eye with damage to the optic nerve head and loss of visual field. This damage is irreversible so treatment of glaucoma is

FIG 3—Diabetic exudative maculopathy (top) just after focal laser and (bottom) three months later when exudates and oedema have partially resorbed

FIG 4—Retinal hole before (left) and after (right) being surrounded by laser burns

designed to prevent further visual loss by reducing the intraocular pressure. Most cases of chronic open angle glaucoma are associated with raised intraocular pressure caused by obstruction of aqueous drainage at the trabecular meshwork. Usually the condition is managed medically with topical or systemic drugs to lower intraocular pressure or by surgery. Open angle glaucoma has also been treated by argon¹³ or diode laser trabeculoplasty,¹⁴ which entails laser photocoagulation of the trabecular meshwork. There are several theories on how laser trabeculoplasty works. Whatever the mechanism of action, effective laser trabeculoplasty reduces the resistance of the trabecular meshwork to aqueous outflow and thus lowers intraocular pressure.

More recently, a new type of YAG laser, the Holmium laser, has been put on trial. This laser is designed to remove a controlled amount of sclera and would replace the traditional trabeculectomy, in which a flap of sclera is lifted and an artificial drainage channel for aqueous from the eye into the subconjunctival space is created.¹⁵ Water in the target tissue absorbs near infrared energy from the Holmium laser, inducing a thermally mediated effect. It remains to be seen whether the Holmium laser will be as convenient or successful as conventional trabeculectomy.

The ciliary body may be ablated by laser energy to reduce the amount of aqueous produced by the eye. This treatment is usually reserved for intractable glaucoma not amenable to other measures, such as rubeotic glaucoma. The continuous mode neodymium-YAG or diode laser is used to treat the ciliary body transsclerally.¹⁶ (The sclera is opaque to visible light but not to the infrared wavelengths produced by the neodymium-YAG and diode lasers.)

Photodisruption

The short pulsed neodymium-YAG laser causes photodisruption. The laser is focused intensely in time and place on a minute volume so that the atomic structure of the target tissue is altered. The laser is fired for nanoseconds at sufficiently high energy levels to generate a "plasma" of atoms surrounded by free electrons. This results in a peak temperature of approximately 10 000°C at the impact site and causes profound disruption of a highly localised area of target tissue with little effect on the surrounding tissues. Pulsed YAG lasers are used for posterior capsulotomy after cataract surgery, and to perform laser iridotomy in angle closure glaucoma.

ABLATION OF THE LENS CAPSULE

Cataracts cannot be treated with lasers. Instead the lens must be removed surgically when it has become opaque. Modern cataract surgery aims at leaving the posterior capsule of the lens intact so that it can be used to support an intraocular lens, giving the patient as near normal vision as possible. This membrane, the posterior capsule of the lens, is only 5 µm thick and very clear, but postoperatively it may thicken and opacify, producing symptoms similar to those of the original cataract. This happens in 12-50% of patients who have had extracapsular cataract extraction¹⁷ but can be simply treated by laser capsulotomy, when neodymium-YAG laser pulses are used to cut through the capsule and restore a clear visual axis (fig 5). It is a relatively safe and simple procedure,¹⁸ and is rewarding as the patient's vision is restored almost immediately.

TREATMENT OF ANGLE CLOSURE GLAUCOMA

In closed angle glaucoma the normal flow of aqueous from behind the iris through the pupil into the anterior chamber is obstructed by occlusion of the pupil by the lens. The pressure rises behind the iris as the ciliary

FIG 5—Posterior capsular thickening seen as opacity behind the pupil (top) before laser treatment and (bottom) after YAG laser has formed a central gap in the opacity

body continues to produce aqueous. This bows the iris forward and the peripheral iris occludes the trabecular meshwork. The occlusion of the trabecular meshwork by the iris exacerbates the rise in intraocular pressure by preventing aqueous from draining into the canal of Schlemm.

The condition tends to present suddenly with an abrupt rise in pressure (acute angle closure glaucoma) causing intense pain and loss of vision through corneal oedema. The rise in pressure is controlled medically, but recurrence of the condition can be prevented by creating an alternative path for aqueous flow through a hole in the peripheral iris (fig 6). Neodymium-YAG laser peripheral iridotomy has tended to replace surgical iridectomy as the treatment of choice for angle closure glaucoma as it takes only minutes to perform and requires only topical anaesthesia.

Chronic angle closure glaucoma presents with gradual loss of vision caused by insidious raised intraocular pressure due to blockage of the trabecular meshwork by the peripheral iris. It may also be treated by laser iridotomy or peripheral iridectomy.

Photoablation

The argon-fluoride excimer beam causes photoablation—interatomic bonds are destabilised by a beam of extremely high energy photons whose depth of penetration is only a few micrometres. The excimer laser produces an ultraviolet wavelength which is highly absorbed by all tissues. This means it can be used to treat only accessible superficial areas such as the cornea. The excimer is a research tool and current work is directed towards refractive surgery and the treatment of superficial corneal opacities.

LASER TREATMENT FOR MYOPIA

Myopia is a refractive error in which the incident light rays are focused in front of the retina—that is, the eye has “too much focusing power”). It is usually caused by the eyeball being too long and is corrected by concave lenses, either in glasses or contact lenses.

Low myopia compensates for presbyopia since it is

always possible for shortsighted people to read by taking off their glasses. Although successful surgical treatment for myopia would remove the need for distance glasses when young, it would make patients dependent on reading glasses when they become presbyopic, and this must be taken into account when advising anyone about the relative merits of correction of myopia by surgery or laser.

At present there are two main permanent treatments for myopia. The best established, radial keratotomy, was developed in Russia and Japan and has been performed extensively in the United States. It involves making four or eight incisions radially in the cornea to 90% of the corneal thickness, which have the effect of flattening it. The results are good in skilled hands,¹⁹ but the cornea is permanently weakened and there is a certain amount of glare from residual corneal scars.

Excimer lasers emit brief pulses of highly energetic ultraviolet light which are absorbed by the superficial cornea. Corneal tissue absorbing this light is vapourised and the laser can be used to remodel the corneal topography. Rather than making radial keratotomy incisions the laser has been used to ablate a thin layer of anterior corneal tissue. Trials currently in progress are promising and it may be that this treatment (photorefractive keratectomy) will replace radial keratotomy in the future.²⁰ Excimer lasers can also be used to remove the calcium deposits in band keratopathy (fig 7).²¹ However, excimer lasers are experimental tools and there are few long term follow up data available at present.

Laser safety

Iatrogenic injuries induced by laser treatment are avoided by meticulous application of laser energy of appropriate wavelengths and by using well maintained machines incorporating safety devices. Observers should wear protective goggles to filter stray laser energy.

The hazard of macular photocoagulation when using the argon blue laser wavelength is not confined to the patient. Ophthalmologists performing argon blue-green laser panretinal photocoagulation stare for a long time at the reflection of a weak blue-green laser aiming beam as they guide the laser across the retina, and it has now been shown that frequent and prolonged use of lasers can damage ophthalmologists' colour vision.²² A protective filter should be placed in the ophthalmologist's viewing pathway to remove the damaging blue argon wavelength.²³

Summary

Current laser treatments are quick, relatively painless, and well tolerated. Some ophthalmic techniques can be performed only by laser while others have a lower morbidity than alternative treatments.

Peripheral retinal photocoagulation and focal photo-

FIG 6—YAG laser iridotomy seen as hole in the peripheral iris

FIG 7—Appearance of the cornea (top) before and (bottom) after excimer laser ablation of the axial portion of superficial band keratopathy

coagulation now offer greatly improved visual prognosis for diabetic patients with proliferative diabetic retinopathy or diabetic macular disease. Selected cases of macular degeneration may be treated by focal laser photocoagulation. The role of lasers in treating sub-retinal neovascular membranes is limited by the extent and location of the membrane at presentation and the high risk of recurrence after treatment. Patients with distorted vision must be referred urgently for specialist ophthalmic assessment.

Flat retinal holes and tears may be sealed by laser therapy, thus preventing retinal detachment. Short pulsed neodymium-YAG photodisruptive capsulotomy effectively clears the visual axis of thickened posterior lens capsule after cataract surgery. Short pulsed neodymium-YAG photodisruptive iridotomy may be used to treat and prevent angle closure glaucoma. Laser trabeculoplasty aids the control of

open angle glaucoma. Research is continuing into the role of other lasers in managing open angle glaucoma and of photoablative lasers in treating refractive errors and superficial corneal disorders.

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ANY QUESTIONS

When Stewart et al established that the most decisive pass/fail criterion for the short Synacthen (tetracosactrin) test was the peak serum cortisol concentration after administration of Synacthen they based their conclusions on tests performed at 9 am.¹ Does this render tests performed at other times of the day invalid?

In 1988 we reported the results of 70 paired short Synacthen tests and insulin tolerance tests performed in patients with pituitary disease suspected of having secondary adrenal insufficiency.¹ The insulin tolerance test remains the gold standard for assessing the adequacy of the hypothalamo-pituitary-adrenal axis but is time consuming, unpleasant, and potentially harmful. To verify previous work indicating that the short Synacthen test could be a useful alternative it was important to ensure that both tests were performed under the same conditions.² The insulin tolerance test requires a patient who has fasted and our group therefore performs it at 8.30 am to 9 am. Hence we used this same time for the short Synacthen test.

One advantage of the short Synacthen test is that it can be performed in the outpatient clinic. After our formal

comparison of the short Synacthen test and insulin tolerance test at 9 am a recent paper by Dickstein et al is particularly important, indicating a similar, though not identical, peak adrenocortical response to the short Synacthen test at 8 am and 4 pm.³ My only slight reservation about this study is that it was carried out in normal volunteers; whether the results apply to patients with failing adrenocorticotrophic hormone drive is unknown. Despite this minor nagging doubt I suspect that the short Synacthen test will continue to be a useful indicator of adequacy of the hypothalamo-pituitary-adrenal axis irrespective of what time of day the test is performed. An inadequate response should be followed up with an insulin tolerance test.—PAUL M STEWART, lecturer in medicine and endocrinology, Birmingham

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