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Photocoagulation in Ophthalmology

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Abstract: Photocoagulation means coagulation of cells and destruction of tissues with the help of excessive brilliant light or laser beam. In the eye, major portion of the incident light or laser beam is absorbed mainly by dark melanin pigments of retinal pigment epithelium and also by pigments of uveal tissues and blood vessels. After absorption, light energy is transformed into thermal energy which coagulates the treated tissue. It also occludes small vessels and causes contraction of smooth muscles and connective tissues. This modality of photocoagulation treatment is utilised in ophthalmology in sealing retinal breaks by producing chorioretinal adhesion, in coagulating undesired new blood vessels, (responsible for retinal haemorrhage and retinopathy, particularly in diabetic retinopathy). It is also used for destruction of small Intraocular tumours and cysts.

The source of light energy is derieved from specially constructed high pressure xenon arc lamp and various types of laser. Argon laser is commonly used for treatment of diabetic retinopathy and other retinal disorders and also in treatment of some types of glaucoma.

Neodynium-Yag laser is used mainly for surgical purposes. Krypton laser is used specifically for treatment of mascular diseases and CO_2 laser is used for endocoagulation, external surgery and also for treatment of glaucoma.

Keywords: Photocoagulation, xenon arc argon laser, krypton laser. Nd-Yag laser, diabetic retinopathy.

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1. Introduction

Plato's phaedo contains a passage in which Socrates admonishes that one must take care not to look directly at the sun during solar eclipse but to view the sun reflection in water. Burning or coagulation effect of solar radiation was known to the ancient physicians in India.

Various workers studied the effect of the beam of sun rays to produce a burn in the retina. Moran Sales was the first to try photocoagulation (P.C.) in experimental animals and human eye but the first publication about cilnical photocoagulation came in 1949. At that time the light source was a carbon arc named Beck Arc, which was not very suitable for its short photocoagulation span and producing gases saturated with shoot and carbon particle. In 1956, high pressure

xenon lamp was used as the photocoagulation source which is still being used as an important modality for P.C.

First optical laser was produced in 1960. A ruby crystal was used to produce a 200 sec pulse of intense red light. The ruby laser was effective in producing adhesions in the retina and choroid but it was not suitable for treating vascular diseases and it is no more in clinical use.

From early 70s argon laser (Blue green), krypton laser and then ND-Yag laser were available for clinical use which revolutionised treatment of ocular conditions like diabetic retinopathy, veinous occlussions, Eales disease, C.S.R., S.R.N.V., capsulotomies with or without I.O.L., membranectomy and some forms of glaucoma.

2. Different types of lasers for photocoagulations

Of the various lasers in clinical practice, argon laser is the most commonly and widely used. Blue Green Argon laser is absorbed by melanin, haemoglobin and xanthophyll pigments. It is not very suitable for treating macular lesions because of its absorption by xanthophyll pigments finally damaging nerve fibers. Krypton laser is ideal for treating S.R.N.V., because of high absorption by choroid and it is excellent for parafoveal coagulation because of no effect on xanthophyll.

Nd-Yag laser is a relatively recent introduction it acts purely by mechanical disruption of tissue because of its ability to generate tremendous power within extremely short time. It is very useful for producing capsulotomies, iridotomies and disruption of vitreous membranes.

2.1. Comparison of modalities of the common lasers for P.C. :

If we compare the two most commonly used modalities for photocoagulation, the xenon arc and the lasers ; we can note that light from xenon arc source is polychromatic contains wave lengths from ultraviolet to infrared inclusive of visible spectrum and suffers from chromatic aberration. It is incoherent and the focal point is not as bright as the light source. The energy delivered per unit area is directly proportional to the spot size. The spot size being quite large, it is not suitable for photocoagulation near fovea. The large infra-red component can lead to shrinkage of vitreous and retina. With all its negative points, even today xenon-arc photocoagulation is quite efficiently being used for treating nearly all ocular conditions requiring P.C. It is preferable in treatment of malignant toumours of retina and choroid. It produces full thickness chorio-retinal coagulation and useful for treating structural defects in retina.

Light from a laser source is monochromatic, coherent, unidirectional and collimated. It delivers high energy in extremely short periods of time and the energy delivered per unit area is inversely proportional to the spot size. It is suitable for selective layer coagulation of retina and choroid and for photocoagula-

tion of macular region. The laser instrument is simple, the light provides a large field of view, requires short exposure time and exit light can be manipulated through a small pupil.

3. Principle of laser

Now, it would not be out of place to discuss some basic aspects of laser or light amplification by stimulated emission of radiation.

All matters radiate electromagnetic radiation. Forty percent of radiation is in the visible spectrum between 400 to 700 nanometers. Lasers can be classified by the materials used as the active medium (solid, liquid or gas) and by their method of operation. Atoms, molecules or ions are capable of becoming excited to a higher energy state by absorption of thermal, electric or optical energy. The basic requirements for any laser are

1. A suitable medium to be lased ;
2. An external power source ;
3. A vessel or chamber to contain the medium ;
4. A focusing system to handle the emission of electromagnetic radiation ;
5. Safety features such as filters for protection.

Argon laser use a gas contained in a glass tube. The gas is energized (pumped) by an external source of electric current. When an energized molecule is struck by a light beam of appropriate wave length, the stored energy is released in the form of an additional beam of light which is of the same wavelength, in phase and parallel to the initial beam forming a coherent light. The laser beam is allowed to escape into the focusing system and is guided by mirrors and focussed by a lens system or directed through a fibre-optic bundle.

3.1. Effects of lasers and their causes :

A. The thermal effects of laser energy are functions of

(i) Absorption of a particular wavelength ;
(ii) Power density ;
(iii) Duration of exposure ;
(iv) Size of radiated area ;
(v) Cooling component (blood flow).

B. The thermal effects produce

Controlled thermocoagulation, Vaporization of tissues.	desired effect.
Coagulation necrosis, and oedema.	undesirable effect.

Lasers in ophthalmology deliver energy either as a continuous wave source or as pulsed wave. In continuous wave one watt is delivered for 0.02 sec, the

pulsed laser uses 25 watts at peak power and pulsates 6 bursts which lasts 120 micro seconds. Perforation of tissue is accomplished with high energy at a short duration.

Spot size	(50-700) $m\mu$
Time	(0.02-0.2 sec).
Energy	(0.1-25 Watts).
Pulses	(10-500 Pulses per second).

C.W.	P.W.
(a) Continuous full power Extreme heat build-up	(a) Full power only as recorded. Minimal heat build-up.
(b) Inefficient energy use If cooling is lost— tube is lost	(b) Efficient energy use. If cooling is lost— no tube damage.
(c) Central cavity with large ring of coagulation necrosis.	(c) Central cavity with minimal tissue damage to surrounding area.

3.2. *Critical characteristics for precise cutting action of laser :*

To achive a mechanical cutting action using light, the light must be in the form of a pulse which is short in duration and concentrated in space. Q switching concentrates the light into a single smooth pulse from 3 to 20 nano seconds (10^{-9} sec) duration. Mode-locking concentrates the light into a series (or 'train') of very short pulse each lasting about 30 picosecond (10^{-12} second).

A Q switched laser (nano second) requires more energy than does mode-locked laser (picosecond to achieve optical breakdown).

3.3. *Short-pulse lasers :*

Short-pulse lasers have recently come into vogue as a non invasive eye surgical phototherapy technique. Nd-Yag laser is an infra red beam consisting of photon which when focussed, force away electron from molecules, producing plasma and shock waves, that in turn rupture the tissues.

4. Clinical aspects of photocoagulation

Now coming back to the clinical aspect the aim of photocoagulation is to maintain the macular physiological structure, haemodynamics and fluid dynamics in a healthy structure. The alterations that can disturb the macula are

(i) Defective adhesiveness of pigment epithelium to Bruch's membrane.

(ii) Degeneration of the pigment epithelium.

(iii) Vascular defects disturbing nutrient and metabolic transport system.

(iv) Proliferation of neovascular tissue. All these are tackled in different ways by photocoagulation either by sealing at the pigment epithelial level or

knocking out leaking retinal vessels or hypoxic areas or even ablating the normal retina in the periphery to save the macula. Photocoagulation can treat permeability defects of the retinal vessels. Localised hypoxia of retina and choroid leads to production of a biochemical stimulus which promotes neovascularisation. Photocoagulation knocks out these hypoxic areas to convert them into atrophic areas so that the biochemical stimulus is lost which stops further process of neovascularisation.

4.1. Investigative procedure prior to photocoagulation :

The most important investigate procedure before photocoagulation is fluroescein angiography. It reveals (a) abnormalities of retinal blood vessels ; (b) breakdown of blood retinal barrier ; (c) areas of capillary closure and (d) retinal and choroidal tumours.

5. Physical processes in photocoagulation

Thermal reaction induced by photons are called photocoagulation. Protein denaturation by heat produces photocoagulation effect and its ocular reactions are in the form of cell proliferation, migration and scar formation.

Energy levels lower than the coagulation power induce a photochemical or thermal reaction, ultraviolet photons induce formation or destruction of chemical bonds which produce thermal reactions whereas visible spectrum produces both chemical and thermal reaction. Extensive absorption of laser energy can produce micro-explosions by raising tissue temperature to the boiling point of water, vasospasms, perivascular changes, obliteration.

Now coming to the diseases treatment by photocoagulation of diabetic retinopathy (P.D.R.) heads the list. With better medical treatment the diabetics are now enjoying a longer life-span but on the other hand, diabetic retinopathy has become the single commonest cause of incurable blindness in the world. Photocoagulation is the only sensible treatment for detachment of retina. Previously main thrust was in treating the neovascular areas directly, but the reports of detachment of retina surgery group in U.S.A., clearly established the usefulness of the indirect approach in the form of pan-retinal photocoagulation (P.R.P.). Cases of advanced background diabetic retinopathy, P.D.R. and cases of maculopathy are selected for photocoagulation. Some cases of maculopathy which also require focal photocoagulation for which krypton laser will be the best.

6. Photocoagulation retinal therapy

In P.R.P. the retina from nasal to the disc and outside the temporal arcade is destroyed upto or beyond the equator. P.R.P. achieves its target of improved oxygen perfusion of macula and reducing vasoproliferative factors by varying combination of factors e.g.

(i) Reduction or elimination of the areas of retinal hypoxia ;

(ii) Greater perfusion from the choroidal circulation by achieving a closer approximation of the inner layers of the retina with choriocapillaries ;

(iii) Diverting the available blood to the central area ;

(iv) Destruction of leaking blood vessels and normalising the vascular supply of the macula. P.R.P. can be performed by xenon arc, argon laser or krypton laser. One thing is certain that P.R.P. is destroying a bulk of retina-unhealthy and healthy. Diabetic retinopathy manifestations are also destroying the retina and some may think that both processes are competitors for destroying the retina. The difference being that when we are destroying the retina we preserve the most useful central area but the disease is not selective. It is like carrying your own bomb for preventing the other bomb from exploding.

P.R.P. is contra-indicated in eyes with extensive glial proliferation or vitreoretinal traction, florid surface neovascularisation and in the presence of massive oedema and exudates with or without associated hypertensive retinopathy.

P.R.P. with argon laser will require 2000 to 3000 spots of 250 to 500 microns size set at 0.1 to 0.2 sec and 250 to 600 millwatts. P.R.P. is also indicated in cases of central retinal vein occlusion and some cases of B.R.V.O. In C.R.V.O. it prevent neovascular glaucoma and micro cystic changes in the macula. Some cases of advanced Eale's disease may require P.R.P. but most cases of Eale's disease will require sector coagulation.

Photocoagulation is a safe and effective way of treating retinal breaks where the retina is not detached. It is very useful in cases of operated retinal detachment and may prevent much troublesome re-operation.

Intraocular tumours like retinoblastoma, malignant melanoma etc. are often treated with photocoagulation. Here xenon arc is preferred to the laser photocoagulators.

Photocoagulation near fovea is required in cases of S.R.N.V. and C.S.R. Recently, some workers have observed that the treated and untreated cases of C.S.R. behave in the same way in the long run.

Though not coming in the group of photocoagulation, lasers are presently being employed in treatment of various glaucomas. Laser iridotomy for angle closure glaucoma and laser trabeculoplasty for open angle glaucoma are the commonly practised procedures.

Nd-Yag laser capsulotomy (with or without I.O.L.), membranectomy etc. has already been discussed.

Lasers have been found useful in treating various anterior segment pathology like coagulation of iris tumours, iris cysts, occuluding vessels in rubeosis iridis, corneal vascularisation and producing photomydriasis or fashioning of new pupil.

7. Limitation of photocoagulation

The dark part of photocoagulation is that it does not cure the disease but in best cases can stabilise the cause and minimise further deterioration. The treatment modality like any other modality is not immuned from side-effects, complications and has some limitations too.

The limitations may come from several factors e.g.,

(i) No more healthy tissue available for photocoagulation ;
(ii) Retinopathy rise factors ;
(iii) Extensive glial proliferation and vitreo-retinal traction ;
(iv) Hypertensive retinopathy renal feature.

Relative limitation may crop up from factors like

(a) Bed-ridden and non cooperative patient ;
(b) Small palpebral fissure ;
(c) Small immobile pupil ;
(d) Hazy media – cornea, lens and vitreous ;
(e) Tractional retinal detachment.

Side effects of photocoagulation are

(i) Temporary reduction of vision ;
(ii) Myopia ;
(iii) Mild iritis ;
(iv) Changes in dark adaptation ;
(v) Colour perception alteration ;
(vi) Field defect ;
(vii) Changes in pupil ;
(viii) Rise of I.O.P.

Other complications are

(a) Macular oedema ;
(b) Localised bleeding ;
(c) Foveolar burn ;
(d) Traction retinal detachment.

8. Future developments in lasers for photocoagulation

The future prospects are so bright that in future we may get a new branch called 'Photosurgery' which will be labelled as "all surgery done in contact or non-contact way with the help of photons," on the other hand the gloomy aspect can be realised from the increasing trend of compensation and medical insurance in Western countries.

8.1 Some salient features of recent lasers are listed below

(i) Dye lasers : Wavelength is tunable from 488 to 680 nanometers by changing the dye. The wave length can be adapted to the structure to be treated.

(ii) Excimer lasers : This is also tunable laser basically used for photo-ablative purpose. Radial keratotomy and keratoconous correction could be possible.

(iii) CO_2 lasers : The wavelength of 10.6 nm makes it useful for extrabulbar applications like removal of tumour, opening of sclera for drainage of S.R.F.

(iv) Erbium lasers : Wavelength of 1.5 nm makes it suitable for capsulotomy without penetration of radiation into the vitreous.

(v) Semiconductor lasers : This operation in new infra-red may make them suitable for photo-acupuncture, photo-anaesthesia etc.

9. Conclusions

With all these modalities, we are only trying to cure the signs and symptoms and not the course to which is added the problem of over-treating or over photo-coagulating.

If we are able to change the cellular contents or activity and could create a molecular rejuvenation, then we will be able to transform the diseased cell (cornea or retina) into healthy ones (young ones) and the cause may be cured.

The care for over-treating or over-photocoagulation would be the use of a computer system that has an autodose program for the various disease.

We can speculate that within next 10 to 20 years, the operation theatre will be filled with robots that will reduce our task to watch a real time image analysis system and the superior human brain solving the problems more efficiently.