REVIEWS

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Therapeutic Application of Lasers in Ophthalmology

Terapeutyczne zastosowanie laserów w okulistyce

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Abstract

Lasers have found application in diverse branches of medicine. In ophthalmology, laser technology has various therapeutic and diagnostic applications. The purpose of this article is to review the major therapeutic applications of lasers in different eye disorders. The effects of lasers on biological tissues and different laser techniques as well as the indications for laser therapy in various parts of the eye are discussed. Lasers are used to treat glaucoma and many vascular disorders of the retina. Laser treatment may be useful in preventing the development of neovascularization in diabetic retinopathy, BRVO, or CRVO. Laser techniques are also available for the treatment of the exudative form of age-related macular degeneration (AMD) and some malignant and benign intraocular tumors and in retina abnormalities which predispose to rhegmatogenous retinal detachment. Corneal laser surgery is the most frequently applied laser procedure in ophthalmology. PRK, LASIK, and LASEK are used to correct errors in vision such as myopia, hyperopia, and astigmatism. Laser photocoagulation is also helpful in cataract surgery. Nowadays, lasers have become so universal that it is difficult to imagine ophthalmology without them. We are still witnessing rapid advances in the development of laser techniques, especially in plastic surgery, cataract extraction, and ocular imaging (**Adv Clin Exp Med 2007, 16, 6, 801–805**).

Key words: laser, eye, treatment.

Streszczenie

Światło lasera znalazło zastosowanie w różnych dziedzinach medycyny. W okulistyce technika laserowa jest stosowana zarówno w diagnostyce, jak i terapii. Celem artykułu jest przegląd najistotniejszych terapeutycznych zastosowań lasera w chorobach oczu. Omówiono wpływ lasera na tkanki oraz różne techniki laserowe wraz ze wskazaniami terapeutycznymi w różnych chorobach oczu. Lasery są używane do leczenia jaskry oraz różnych naczyniowych chorób siatkówki. Są pomocne w zapobieganiu rozwojowi neowaskularyzacji w retinopatii cukrzycowej, w zakrzepie gałązki bądź żyły centralnej siatkówki. Terapia laserowa jest także stosowana w leczeniu wysiękowej postaci zwyrodnienia plamki związanego z wiekiem (AMD), niektórych złośliwych i łagodnych guzów wewnątrzgałkowych oraz w zmianach siatkówki prowadzących do jej odwarstwienia. Jedną z najczęściej stosowanych procedur laserowych w okulistyce jest laserowa chirurgia rogówki. PRK, LASIK oraz LASEK są stosowane do korekcji wad wzroku, takich jak: krótkowzroczność, nadwzroczność lub astygmatyzm. W obecnych czasach lasery stały się tak powszechne, że trudno wyobrazić sobie okulistykę bez nich. Wciąż jesteśmy świadkami szybkiego postępu w rozwoju technik laserowych, przede wszystkim w chirurgii plastycznej, chirurgii zaćmy oraz w obrazowaniu gałki ocznej (**Adv Clin Exp Med 2007, 16, 6, 801–805**).

Słowa kluczowe: laser, oko, leczenie.

The effects of lasers on biological tissues can be divided into three general categories: photochemical, thermal, and ionizing. With the improvements in laser technology, techniques applying different types of lasers, e.g. ruby, neodymium, neodymium:yttrium-aluminum-garnet (Nd:YAG), erbium, and argon, allow utilizing lasers in the treatment and diagnostics of many eye disorders.

Photoradiation is used in the management of tumor tissues, which are exposed to laser light to heat the tumor, causing photochemical damage and necrosis. Photoablation is a procedure in which disintegration of the intermolecular bands of biological tissue causes its decomposition and subsequent removal. This can be effected with, for example, an excimer laser. Photocoagulation is a result of the direct absorption of laser energy by pigmented tissues. The process of coagulation depends on the temperature level, with 60 C or more causing the denaturation of biomolecules. The absorption of certain light frequencies is high in the pigmented trabecular meshwork, iris, ciliary body, and retinal pigment epithelium (owing to melanin) and in blood vessels (owing to hemoglobin). Lasers commonly used for photocoagulation are argon, krypton, or diode Nd:YAG lasers.

Photovaporization occurs when the tissue temperature quickly reaches 100 C or more, causing disruption (evaporation) before denaturation (photocoagulation). Lasers used for this interaction are holmium:YAG or erbium:YAG lasers in sclerostomy. In photodisruption, short-pulsed high-power lasers are focused on a very small area, causing disruption of tissues by delivering high energy. The tissue is rapidly heated and transformed into plasma, which is a collection of ions and electrons. This plasma initiates an acoustic shock wave that mechanically disrupts tissues adjacent to the region of the laser's focal point [1]. Examples of photodisrupter lasers are the Q-switched and pulsed Nd:YAG lasers.

The laser treatment of glaucoma is often recommended when medical therapy alone is insufficient in controlling intraocular pressure and for those patients who have contraindications to glaucoma medications or who are unable to use eye drops for any reason. The most common glaucoma laser procedure is laser peripheral iridotomy (LPI). Laser iridotomy replaced invasive surgical iridectomy as the treatment of choice in patients with narrow-angle, acute-angle closure glaucoma, in the fellow eye of patients with acute or chronic primary angle closure, or pupillary-block glaucoma [2]. Laser peripheral iridotomy creates complete perforation in the peripheral one third of the iris, allowing aqueous fluid to flow from behind the iris directly to the anterior chamber of the eye. This changes the convex configuration of the iris and thereby opens the angle of the eye [3].

Nowadays there are two types of lasers used for LPI: the Nd:YAG Q-switched laser (2–8 mJ) and the argon laser (800–1000 mW). The argon laser started to replace surgical iridectomy as the first-line treatment in the late 1970s. It was demonstrated to be safe and effective [4], but required melanin for tissue absorption of energy. The Nd:YAG laser replaced argon in the late 1980s and is used more often because it is faster, easier to perform, causes less inflammation, and is not dependent on the presence of melanin pigment. The Q-switched mode of the Nd:YAG laser causes the photodisruption of tissues using less overall energy than an argon laser. Complications of laser iridotomy include irritation, blurred vision, iritis, iris hemorrhage, elevated intraocular pressure, corneal injury, and retinal burns.

Argon laser trabeculoplasty (ALT) is a procedure which has been proven to be efficacious for different types of open-angle glaucoma: primary open-angle glaucoma, pseudoexfoliation glaucoma, and pigment dispersion glaucoma. Patients with uncontrolled glaucoma can benefit from ALT before another surgical intervention is considered [5]. In the ALT procedure, the laser is focused on the trabecular meshwork, which is the primary aqueous drainage region of the eye. With a spot size of 50 µm, 180 or 360 degrees of the trabecular meshwork is treated with the laser. The laser parameters should be adjusted during the treatment session individually to achieve a visible blanching of the pigmented trabecular meshwork. The effect of the procedure is increased drainage of aqueous fluid out of the eye, with a mean reduction in intraocular pressure of 6–9 mm Hg (20–30%). The results of the ALT procedure last for about 5 years.

A modification of this procedure is selective laser trabeculoplasty (SLT) performed with a 532-nm frequency-doubled Q-switched Nd:YAG laser using low energy, a short pulse duration, and a large spot size. SLT selectively targets pigmented trabecular meshwork cells without damaging adjacent non-pigmented trabecular meshwork cells and underlying trabecular beams [6]. Therefore, unlike ALT, SLT can be repeated several times. Indications for this procedure and potential complications (postoperative inflammation, intermittent intraocular pressure elevation, and hemorrhage) are similar to those of ALT.

Another glaucoma laser procedure is argon laser peripheral iridoplasty (ALPI). ALPI is a method to alter the configuration of the angle to relieve the appositional closure using the thermal effect. This procedure can be used in situations in which laser iridotomy cannot be performed or does not eliminate appositional angle closure. The argon laser is set to produce contraction burns of low power (80–100 mW), long duration (up to 0.7 second), and large spot size (500 µm) in the extreme iris periphery. Contraction of the iris stroma between the site of the burn and the angle widen the angle approach. ALPI is recommended in plateau iris syndrome and angle-closure glaucoma [7, 8].

Cyclodestructive procedures for glaucoma lower the intraocular pressure (IOP) by reducing aqueous inflow as a result of destruction of ciliary processes. The use of light energy to destroy the ciliary body was first proposed by Weekers and coworkers in 1961 using xenon arc photocoagulation [9]. In 1972, Beckman and Waeltermann performed the first transscleral cyclophotocoagulation (TSCPC) procedure with a ruby laser [10]. Since then, Nd:YAG and diode lasers have been used for either contact or non-contact as well as continuous and pulsed transscleral cyclophotodestruction. These procedures are usually reserved for uncontrolled open-angle glaucoma in eyes with poor visual potential, neovascular glaucoma, traumatic glaucoma, and glaucoma refractory to other forms of therapy of iridocorneal endothelial syndrome. Cyclophotocoagulation has a high complication rate, including loss of vision and phtisis; therefore it must be considered very carefully in the management of difficult glaucoma cases.

Laser coagulation treatment of the retina was introduced to ophthalmology around the middle of the last century. It is commonly used for the treatment of diabetic retinopathy and other pathological vascular disorders. Retinal laser photocoagulation can be used to close areas of leakage from the blood vessels that cause macular edema or to coagulate areas of ischemia, thus improving retinal oxygenation. Diabetic retinopathy is one of the leading causes of blindness in western countries. Its classification includes background retinopathy and preproliferative and proliferative retinopathy. The most common cause of the decrease in vision is macular edema, which may be connected with either nonproliferative or proliferative retinopathy. Poor control of both blood glucose and blood pressure is usually the most important factor associated with the progression of diabetic retinopathy. Laser photocoagulation remains the only procedure recommended for severe nonproliferative or proliferative retinopathy and maculopathy [11]. The Diabetic Retinopathy Study (DRS) showed that the rate of severe visual loss in high-risk proliferative diabetic retinopathy can be reduced by 60% with accurate application of panretinal photocoagulation therapy [12]. Results from the Early Treatment Diabetic Retinopathy Study (ETDRS) demonstrated that focal laser photocoagulation treatment of the macula region could substantially reduce the risk of visual acuity loss in patients with clinically significant diabetic macular edema [13].

Retinal vein occlusion (RVO) is a common retinal vascular disorder that is often associated with sudden, persistent, and painless visual loss. There are two forms of retinal vein occlusion: branch retinal vein occlusion (BRVO), which may be asymptomatic if located in the nasal quadrants, and central retinal vein occlusion (CRVO). In branch retinal vein occlusion there is usually sclerosis of the corresponding branch retinal artery. Atherosclerosis, turbulent blood flow, and uncontrolled hypertension are risk factors in the development of BRVO. The branch occlusion is most commonly located in the superotemporal quadrant. Central retinal vein occlusion (CRVO) is a closure of the final retinal vein located at the optic nerve's head. CRVO can be divided into two forms: ischemic, defined as greater than the 10 disc area of capillary nonperfusion, and non-ischemic. There is currently no effective treatment available to prevent or restore visual loss from acute CRVO [14]. Patients with CRVO can lose vision secondary to its complications, i.e. macular edema, ischemic maculopathy, neovascular glaucoma, and rhegmatogenous detachment. Argon or diode laser treatment may be useful in managing these complications. Scatter laser treatment should be applied in patients with BRVO to prevent the development of neovascularization. In CRVO, panretinal argon laser photocoagulation treatment may be helpful in preventing neovascular glaucoma.

Nowadays, laser treatment is also available in age-related macular degeneration (AMD). As the ability to perform such visual functions as reading, driving, or sewing depends on the macula, macular degeneration affects everyday life and causes significant vision loss in people over the age of 50. AMD has two basic forms: dry and exudative. Dry AMD is the milder form of the disorder and accounts for about 90% of cases. Exudative (wet) AMD affects only 10–20% of all patients with AMD, but leads to severe vision loss. This form of AMD is characterized by choroidal neovascular lesions and abnormal vessels which grow under the retina, causing leakage. There are two basic forms of laser treatment for exudative AMD: conventional argon or diode laser photocoagulation and a new technique involving photodynamic therapy (PDT). The conventional laser causes thermal injury to the abnormal blood vessels and in this way stops the leakage. However, it also burns the overlying normal retina and can cause irreversible damage to these structures, with subsequent decreased vision. Additionally, laser coagulation is effective only in the treatment of selected cases with small, well-defined, and extrafoveal choroidal neovascularization. The principal of the new treatment for exudative AMD is to damage the subretinal choroidal neovascularization (CNV) while preserving the adjacent surrounding tissues, such as the neurosensory retina and retinal pigment epithelium (RPE) [15]. PDT therapy involves two main steps: intravenous administration of a substance known as verteporfin and activation of the drug by a red laser of a specific wavelength (689 nm). The non-thermal laser light induces a photochemical reaction that leads to the occlusion of the abnormal blood vessels causing leakage in the area of CNV.

The first attempts to treat intraocular tumors by laser photocoagulation were conducted in the late 1950s by G. Meyer-Schwickerath with the xenon arc photocoagulator [16]. Nowadays, lasers are a universal tool in the management of choroidal melanomas and other malignant lesions. Transpupillary thermotherapy (TTT) is a recently popularized method for treating small melanomas [17]. With this technique the infrared radiation of the laser system causes tumor necrosis and leaves a chorioretinal scar. Depending on the clinical circumstances, TTT is often used in combination with other treatment modalities, such as plaque radiotherapy for medium or some large melanomas. With regard to the advantages of laser treatment and a focus on earlier treatment of small lesions, TTT offers high precision during the treatment, reproducibility, and safety for the adjacent tissues.

Refractive surgery with an excimer laser to reduce or eliminate the need for glasses is the most frequently applied laser procedure in medicine. The interaction between corneal tissue and the excimer laser was first investigated in 1981 by Taboada, who studied the response of the epithelium to the argon fluoride (AF) and krypton fluoride (KrF) excimer lasers [18]. The goal of refractive surgery is to correct refractive errors by reshaping the anterior corneal curvature according to its topography and this is achieved by different laser techniques. These techniques, such as radial keratotomy (RK), photorefractive keratectomy (PRK), and laser *in-situ* keratomileusis (LASIK), are used to correct optical aberrations of the eye such as myopia (nearsightedness), hyperopia (farsightedness), and astigmatism (corneal irregularity). During PRK for the correction of myopia, the excimer 193-nm UV laser causes flattening of the central cornea by the ablation of a precise quantity of the stromal tissue. Clinical studies reported refractive success rates of between 80 and 95% for corrections up to –6 D of myopia [19]. LASIK, a modification of this technique, involves creating a corneal flap with a microkeratome blade followed by refractive ablation of the exposed stromal bed with a laser. This flap is then replaced to its original position, usually accomplished without the need for sutures. This procedure is particularly recommended for myopic corrections of more than –6 diopters. In recent years, a new method has been developed and put to use. This is called laser-assisted subepithelial *in-situ* keratomileusis (LASEK) [20]. In this procedure, surgical ablation of the stroma is made with prior removal of the epithelial layer. After the laser treatment, which is equivalent to PRK, the epithelium is replaced.

Laser photocoagulation is also largely used in retinal abnormalities such as tears, breaks, holes, lattice degeneration, and degenerative retinoschisis, which predispose to rhegmatogenous retinal detachment. Some cases may be asymptomatic, but in others, symptoms of flashes, floaters, or loss of peripheral field of vision may occur. Argon laser photocoagulation creates a thermal burn around the lesion, causing adhesion between the retina and retinal pigment epithelium (RPE). This prevents the potential flow of fluid from the vitreous cavity through a break to the subretinal space.

Visual loss occurring secondary to opacification of the posterior capsule after extracapsular cataract extraction is the major indication for laser capsulotomy. Posterior capsulotomy to create a hole in an opacified posterior capsule can be performed with an argon laser or a pulsed Nd-YAG laser.

Nowadays, lasers have become so universal that it is difficult to imagine ophthalmology without them. The rapid explosion of argon laser techniques had a dramatic impact on the treatment of many different ocular disorders and lasers sometimes replaced previously used operative procedures. In the 1990s, another breakthrough occurred in the treatment of posterior segment disorders, including macular degeneration and intraocular tumors. There are also rapid advances in the development of lasers for plastic surgery, cataract extraction, and ocular imaging, and it is hoped that this will continue in the coming years.

References

[1] Gaasterland DE, Mainmaster MA: Clilnical laser physics and laser safety. In: The glaucomas. Eds.: Ritch R, Shields MB, Krupin T. St. Louis: Mosby, 1996, 2nd ed., 1535.

[2] Schwartz GF, Steinmann WC, Spaeth GL, Wilson RP: Surgical and medical management of patients with narrow anterior chamber angles: comparative results. Ophthalmic Surg 1992, 23 2, 108–112.

[3] Jin JC, Anderson DR: The effect of iridotomy on iris contour. Am J Ophthalmol 1990, 110, 260–263.

[4] Quigley HA: Long-term follow up of laser iridotomy. Ophthalmology 1981, 88, 218–224.

[5] Friedman DS, Nordstrom B, Mozaffari E, Qiugley HA: Variations in treatment among adult-onset open-angle glaucoma patients. Ophthalmology 2005, 112, 9, 1494–1499.

[6] Holz HA, Lim MC: Glaucoma lasers: a review of the newer techniques. Curr Opin Ophthalmol 2005, 16, 2, 89–93.

[7] **Lai JS, Tham CC, Chua JK, Poon AS, Lam DS:** Laser peripheral iridoplasty as initial treatment of acute attack of primary angle-closure: A long-term follow-up study. J Glaucoma 2002, 11, 484–487.
[8] **Ritch, R, Tham CC, Lam DS:** Long term success of argon laser peripheral iridoplasty in the management of plateau iris syndrome. Ophthalmology 2004, 111, 1, 104–108.
[9] **Weekers R, Lavergne G, Watillon M, Gilson M, Legros AM:** Effects of photocoagulation of ciliary body upon ocular tension. Am J Ophthalmol 1961, 52, 156–163.
[10] **Beckman H, Waeltermann J:** Transscleral ruby laser cyclocoagulation. Am J Ophthalmol 1984, 98, 6, 788–795.
[11] **Porta M, Allione A:** Current approaches and perspectives in the medical treatment of diabetic retinopathy. Pharmacol Ther 2004, 103, 2, 167–177.
[12] The Diabetic Retinopathy Research Group: Preliminary report on effects of photocoagulation therapy. Am J Ophtahmol 1976, 81, 383–396.
[13] Early Treatment Diabetic Retinopathy Study Group: Photocoagulation for diabetic macular edema: ETDRS report number 1. Arch Ophthalmol 1985, 103, 1796–1806.
[14] **Leonard BC, Coupland SG, Kertes PJ, Bate R:** Long-term follow-up of a modified technique for laser-induced chorioretinal venous anastomosis in nonischemic central retinal vein occlusion. Ophthalmology 2003, 110, 948–954.
[15] **Awan MA, Tarin SA:** Review of photodynamic therapy. Surgeon 2006, 4, 4, 231–236.
[16] **Meyer-Schwickerath G:** Light coagulation. St. Louis, MO: CV Mosby 1960.
[17] **Journee-de Korver JG, Oosterhuis JA, Kakebeeke-Kemme HM, De Wolff-Rouendaal D:** Transpupillary thermotherapy (TTT) by infrared irradiation of choroidal melanoma. Doc Ophthalmol 1992, 82, 185–191.
[18] **Taboada J, Mikesell GW, Reed RD:** Response of the corneal epithelium to krypton fluoride excimer laser pulses. Health Phys 1981, 40, 5, 677–683.
[19] **Seiler T, McDonnell PJ:** Excimer laser photorefractive keratectomy. Surv Ophthalmol 1995, 40, 89–118.
[20] **Camellin M:** Subepithelial corneal ablation. Ocul Surg News Int Edition 1999, 3, 14.

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