Available online at www.sciencedirect.com
ScienceDirect
Physics Procedia 5 (2010) 631–636
Physics Procedia
www.elsevier.com/locate/procedia
LANE 2010

Lasers in Ophthalmology

Christian Y. Mardin*, Ralf P. Tornow and Friedrich E. Kruse

Department of Ophthalmology, Friedrich-Alexander-University Erlangen-Nürnberg, 91054 Erlangen, Germany

Invited Paper

Abstract

Lasers are widely used in Ophthalmology. The unique transparent tissues of the eye's cornea, lens and vitreous body make lasers an ideal medium for diagnosis and therapy. They are incorporated in well established commercially available ophthalmic instruments but they also play an important role in new developments and research work. This paper gives a short overview on selected laser applications in our department.

Keywords: Laser; Ophthalmology; Eye; Glaucoma; Diagnosis; Therapy;

1. Introduction

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. One year after the introduction of the first ruby laser ophthalmology was in 1961 first to apply it in medicine. Again one year after the invention of the argon laser it was the field of ophthalmology applying it for the first time on the human retina. This was followed by the introduction of the Q-switched Nd:YAG-laser in 1977 and the Excimer laser in 1983.

In Ophthalmology, the laser is used in a wide spectrum of diseases, involving both anterior segments (cornea, lens, iris) and posterior segments (retina, choroidea, sclera) of the eye (Fig. 1). In the most important eye diseases like diabetic retinopathy, age-related macular degeneration, glaucoma and cataract, lasers have become a very important tool for diagnostics and therapy. One of the outstanding features of lasers for the application in ophthalmology is the possibility to change the parameters like wavelength, intensity, pulse duration, spot size etc. in an enormous range. In this way, laser-tissue interaction can be optimized; it can be changed from diagnostics to therapy in the same tissue. For instance, laser parameters can be selected so that the cornea acts as a transparent medium with very low absorption and scattering allowing imaging of the retina with high resolution. On the other hand, changing laser parameters leads to high light absorption in the cornea that can be used for corneal tissue ablation. Another important advantage in Ophthalmology is that the laser light can be applied contact-free and therefore the usage is non invasive.

* Corresponding author. Tel.: +49-9131-85-34478; fax: +49-9313-85-36435
E-mail address: Christian.mardin@uk-erlangen.de.

1875-3892
doi:10.1016/j.phpro.2010.08.091

Lasers are incorporated in well established commercially available ophthalmic instruments, but they also play an important role in new developments and research work. The presentation of all possible application of lasers in Ophthalmology goes beyond the scope of this paper. Instead, selected applications of lasers in ophthalmology are described, that are currently under development or in clinical use in our department.

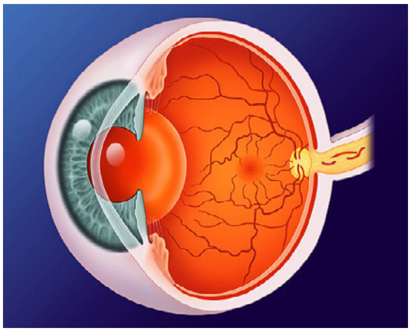

Fig. 1. Schematic diagram of the eye showing the anterior segments (cornea, iris, and lens) and the posterior segments (retina, choroidea, and sclera) and the optic nerve head. The posterior compartment of the eye is filled with transparent gel-like vitreous body.

2. Lasers in diagnostics

Besides from the invention of the laser, ophthalmic diagnostic could additionally benefit from the development of the confocal scanning laser ophthalmoscope (cSLO) [1] and optical coherence tomography (OCT) [2]. The confocal SLO gives crisp retinal images with high contrast using laser light of different wavelength without dilation of the pupil and OCT allows a cross sectional view of ocular structures, especially the retina, with high depth resolution using low-coherence light sources. The following sections show some selected clinical applications of scanning laser ophthalmoscopy and optical coherence tomography.

2.1. Anterior segment imaging

The cornea is a transparent, dehydrated tissue with a central thickness of about 550 µm and a refractive power of about 43 diopters (equates a curvature radius of about 7.7 mm). A cross section of the cornea and complex anatomy can be measured in vivo with the OCT (Fig. 2) and the corneal structures can be visualized with confocal scanning-laser-technique down to cellular structures (Fig. 3).

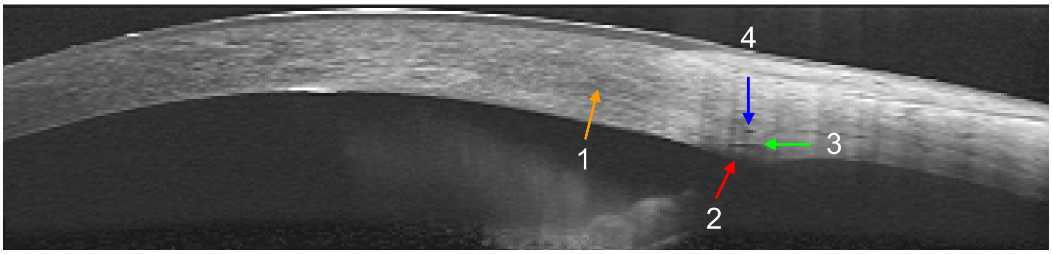

Fig. 2. Cross sectional view of the human cornea (1), trabecular meshwork (2), Schlemm's canal (3) and aqueous veins (4) in the chamber angle

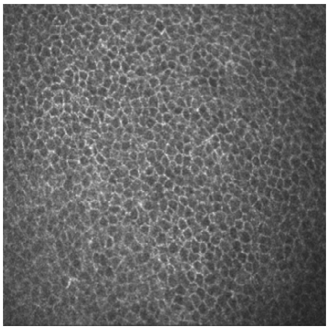

Fig. 3. Top view of the cornea showing corneal epithelial cells in vivo. The image was taken using a confocal laser-scanning Heidelberg Retina Tomograph (HRT III) with Rostock Cornea Module (Heidelberg Engineering)

Both imaging modalities are important to understand eye diseases like the dry eye and to develop new surgical techniques e.g. femtosecond (fs) procedures.

2.2. Optical coherence tomography in glaucoma

Glaucomas are the leading cause for blindness in the world and are characterized by relatively elevated intraocular pressure, resulting in a specific atrophy (tissue damage) of the optic disc and thinning of the retinal nerve fibre layer (RNFL) with increasing visual field loss (Fig. 4). As glaucoma is a treatable disease, the detection of beginning glaucoma can prevent blindness.

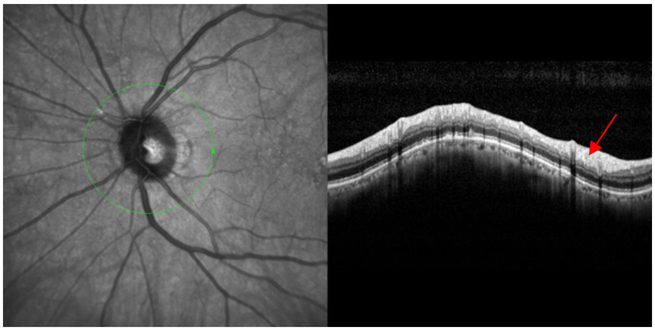

Fig. 4. Infrared reflection image (left) and OCT-B-scan image (right) of a normal subject. The green circle on the left side shows the position of the B-scan. The retinal nerve fiber layer is the most upper bright layer in the cross section (red arrow). Images were taken using a dual laser confocal scanning laser ophthalmoscope (Spectralis HRA&OCT, Heidelberg Engineering, Germany). This instrument is equipped with an 820 nm laser diode for confocal imaging and an 870 nm super luminescent diode for OCT scans

Accurate and reliable measurements of RNFL thickness and knowledge of the normal limits of RNFL is of clinical importance in early glaucoma diagnosis. A study was conducted to obtain clinical data from normal individuals to establish normal limits of the peripapillary RNFL measured with this instrument [3].

2.3. Autofluorescence in glaucoma

Parapapillary atrophy is associated with progressive optic disc damage and visual field loss in glaucoma. Histologic and spectroscopic results revealed an accumulation of lipofuscin as the dominant fundus fluorophore localized in the lysosomes of the retinal pigment epithelium in the parapapillary atrophic zone. Lipofuscin in the retinal pigment epithelium derives mainly from incomplete degradation of outer photoreceptor segments and consists of various components, as lipids, proteins and retinoids - some of them seem to have toxic effects. Scanning laser ophthalmoscopy enables the detection of fundus autofluorescence level and distribution in vivo with high resolution and reproducibility. The Heidelberg Retina Angiograph HRA (Heidelberg Engineering) uses an Argon-Blue-Laser (488nm) for excitation and a barrier filter for detection of emitted light above 500 nm. An autofluorescence image sequence is obtained, automated alignment and averaged to improve signal to noise ratio by image analysis software. In order to quantify autofluorescence changes a semiautomatic approach was developed [4]. Experimental studies suggest that shear forces resulting from intraocular pressure fluctuation may be a risk factor for the development of enlarged parapapillary atrophy (Fig. 5). These findings are in agreement with our findings demonstrating increased autofluorescence properties in the parapapillary region in patients with ocular hypertension and more clearly in primary and secondary open angle glaucoma.

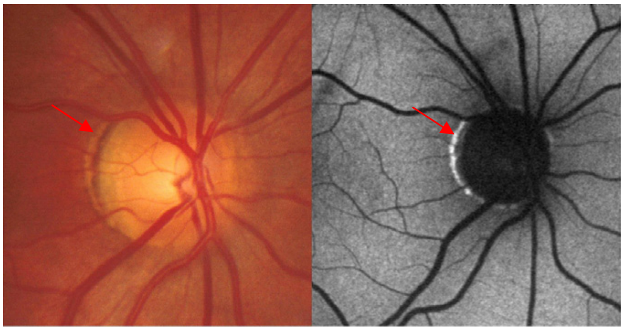

Fig. 5. Color picture (left) and autofluorescence image (right) from one patient with ocular hypertension demonstrating high autofluorescence mainly in the temporal parapapillary region, which appears as orange pigment on the border of the parapapillary atrophic zone alpha (red arrows). The images were taken with a flood illumination fundus camera with white light xenon flash illumination (left) and a confocal scanning laser ophthalmoscope (HRA, Heidelberg Engineering) in autofluorescence mode with 488 nm laser illumination

An increase of parapapillary autofluorescence in patients with ocular hypertension in comparison to the control group could indicate a cumulative deposition of lipofuscin material as potential precursor of increasing parapapillary atrophy and an early indicator for progression in this disease [5].

3. Laser in therapy

The German ophthalmologist Gerhard Meyer Schwickerath (*1920 – †1992) changed medical history with his vision of ‚captured sun light' substantially: Sun light was instrumentalized and applied for the first time by him in ophthalmic surgery. His scientific results laid the fundament for modern laser surgery. Nowadays, a large variety of different lasers are used for surgery and therapy in ophthalmology. The following sections show some clinical applications of lasers in therapy.

3.1. Refractive surgery

Laser in the ultraviolet spectrum with a pulse length of femtoseconds are used in refractive surgery of the cornea. Excimer lasers are also applied to cut the cornea to perform a light-mechanical perforating keratoplasty [6] (Excimer keratoplasty). Contact free excision of corneal tissue is minimal-invasive and allows a high precision.

3.2. Laser therapy in Glaucoma

One of the main therapeutical principles to lower intraocular pressure is the enhancement of the outflow facility from the anterior chamber of the eye. Coagulation of the ciliary body and laser ablation of the trabecular meshwork have been in use in glaucoma surgery for a long time.

4. New developments

4.1. Two-photon technique

Multiphoton imaging combines diagnosis on a cellular level with the option of ablation in the micron range. We explored the potential application of multiphoton imaging for visualization and simultaneous ablation of trabecular tissue for non-invasive glaucoma surgery [7]. A compact solid-state mode-locked 90 MHz Ti:saphire femtosecond laser with a wide wavelength range (715-930 nm) and 140 fs pulse duration, connected to a modified multiphoton laser scanning microscope Zeiss Axiovert 510-Meta was used to *visualize* and *ablate* trabecular meshwork and anterior segment tissues in anaesthetized mice and rabbits (Fig. 6). In vivo multiphoton-autofluorescence imaging and ablation by femtosecond laser pulses within TM is possible from the outerface, and may prove to be a clinically applicable novel option for minimal-invasive trabecular surgery.

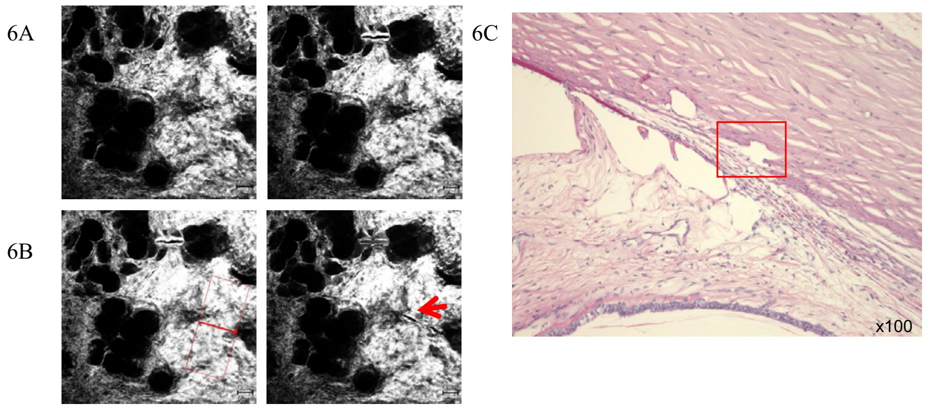

Fig. 6. Right, 6C: Overview histographic slide (conventional light microscope) of a rabbit chamber angle and target area [7]. Left, 6A and 6B: Details of the trabecular meshwork and aqueuos plexus (red square) (rabbit). Images were acquired using two photon technology. (6A) before ablation (6B red square) and after ablation (6B red arrow) (850 nm, z=80 µm, 250 mW, 3.2 µs pixel residence time and 4 s cut time). The same instrument was used for imaging and ablation

4.2. Phacoemulsification of opaque lens matter

Phacoemulsification (ultra sound induced fragmentation) of opaque lens matter with preservation of the capsular bag is the aim of modern cataract surgery. An alternative to the application of ultrasound pulses is the Dodick Laser Photolysis. It applies a 1064 nm Nd:YAG-Laser pulse on a titan target with the result of a shock wave at the tip, disrupting the lens nucleus without harming the thin capsular bag.

The capsular bag of the human lens after phacoemulsification of the lens matter is another target for laser applications. Microscopic remnants of lens epithelial cells lead to secondary cataract formation after surgery. This results in opacification in the visual axis leading to decreased vision. By Nd:YAG-laser disruption of the posterior lens capsule the central part can be cleared up without opening of the eye. But laser pulses increase the risk of vitreous traction of the retina and so the risk for a retinal detachment leading to blindness. Intraoperative cell ablation of the lens epithelium cells in the capsular bag should prevent a postoperative opacification. Laser ablation is performed with the tip of the ARC-laser photolysis system by shock waves of a single laser pulse sparing the posterior lens capsule with a thickness of only 7µm. A 1064 nm Q-switched Nd:YAG-laser with a pulse duration of 4 ns and an energy of 7 to 10 mJ is applied (Fig. 7) [8].

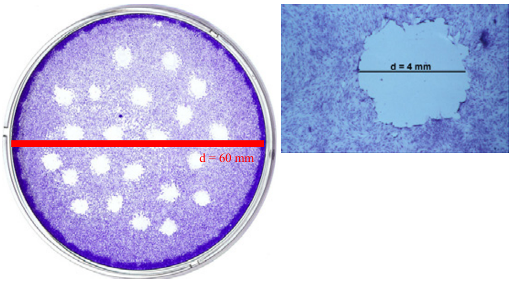

Fig. 7. Lens epithelial culture on a Petri's plate. Nearly circular ablation of lens epithelial cells in culture on plastic plate surface. Nearly complete polish in the ablation zone, independent of pulse energy (left overview, right detail red square)

4.3. Selective Retina Therapy

The minimal invasive, focal coagulation of the retinal pigment epithelium is a valuable addition to the established laser coagulation which has been widely used since the end of the 1970's. A large variety of retinal diseases are treated like diabetic retinopathy, retinal vessel occlusions or retinal breaks. Selective laser therapy with a selective subthreshold coagulation of the retinal pigment epithelium is bound to spare the valuable photoreceptors by ultrashort pulses. Even a proliferating (enhancing growth) effect of the neighboring RPE cells in the case of age-related macular degeneration could have been shown in the past [9].

Acknowledgements

The authors thank all members of their department who contributed to this paper.

References

[1] R.H. Webb, G.W. Hughes, F.C. Delori, Confocal scanning laser ophthalmoscope, Appl. Opt., 26 (1987) 1492-1499.

[2] D. Huang, E.A. Swanson, C.P. Lin, J.S. Schuman, W.G. Stinson, W. Chang, M.R. Hee, T. Flotte, K. Gregory, C.A. Puliafito, et al., Optical coherence tomography, Science, 254 (1991) 1178-1181.

[3] D. Baleanu, R.P. Tornow, F.K. Horn, R. Laemmer, C.W. Roessler, A.G. Juenemann, F.E. Kruse, C.Y. Mardin, Retinal Nerve Fiber Layer Thickness in Normals Measured by Spectral Domain OCT, J Glaucoma, (2009).

[4] R. Kolar, J. Jan, R. Laemmer, R. Jirik, Semiautomatic detection and evaluation of autofluorescent areas in retinal images, Conf Proc IEEE Eng Med Biol Soc, 2007 (2007) 3327-3330.

[5] R. Laemmer, F.K. Horn, A. Viestenz, B. Link, A.G. Juenemann, C.Y. Mardin, Measurement of autofluorescence in the parapapillary atrophic zone in patients with ocular hypertension, Graefes Arch Clin Exp Ophthalmol, 245 (2007) 51-58.

[6] A. Behrens, B. Seitz, M. Kuchle, A. Langenbucher, M.M. Kus, C. Rummelt, G.O. Naumann, "Orientation teeth" in non-mechanical laser corneal trephination for penetrating keratoplasty: 2.94 microm Er:YAG v 193 nm ArF excimer laser, Br J Ophthalmol, 83 (1999) 1008-1012.

[7] P. Pogorelov, U. Schlotzer-Schrehardt, E. Chankiewitz, M. Pollhammer, C. Rummelt, I. Riemann, C. Hammer, E. Lutjen-Drecoll, F.E. Kruse, Multiphoton Imaging for Visualization and Ablation of the Trabecular Meshwork - A New Approach to Glaucoma Surgery, in: Invest. Ophthalmol. Vis. Sci., 2008, pp. 2881, ARVO Abstract.

[8] M.J. Pollhammer, C. Wuellner, R. Tornow, P. Pogorelov, C. Donitzky, F.E. Kruse, Refractive Surgery With a New UV-Femtosecond Laser: Safety Profile and Basic Considerations, in: Invest. Ophthalmol. Vis. Sci., 2008, pp. 3359, ARVO Abstract.

[9] J. Roider, R. Brinkmann, C. Wirbelauer, H. Laqua, R. Birngruber, Subthreshold (retinal pigment epithelium) photocoagulation in macular diseases: a pilot study, Br J Ophthalmol, 84 (2000) 40-47.