Photochemical effects in the lens from near infrared radiation?

Per Söderberg*[a,b,NF], Riyadh Al-Saqry[a,NF], Karl Schulmeister[c,NF], Konstantin Gallichanin[a,NF], Martin Kronschläger[a,NF], Yu Zhaohua[a,NF]
[a]Dept. Of Neuroscience, Ophthalmology, Uppsala University, Uppsala Sweden
[b]Dept. of Biomedical Engineering, University of Miami, Miami, Florida
[c]Austrian Research Centers, Health Physics Division, Seibersdorf, Austria

ABSTRACT

Conclusion: The current data are consistent with a potential photochemical effect of in vivo exposure of the crystalline lens to near infrared radiation since the onset of cataract after in just above threshold dose was at least 18 hrs delayed after the exposure. Materials and methods: The eyes of 6 weeks old Sprague-Dawley rats were exposed unilaterally in vivo to 1090 nm, 6.2 W quasi-top hat spatial distribution with a 3 mm spot on the anterior lens surface within the dilated pupil. First, four exposure time groups of rats were exposed to increasing exposure times. At 24 hrs after exposure, the difference of light scattering between the lenses from the same animal was measured. Then, based on the first experiment, four post-exposure time groups were exposed unilaterally in vivo to 8 s of 1090 nm, 6.2 W quasi-top hat spatial distribution with a 3 mm spot on the anterior lens surface within the dilated pupil. After, the intended post-exposure time, the difference of light scattering between the lenses from the same animal was measured. Results: A 3 mm spot of 6.2 W induces light scattering in the lens with exposures of at least 8 s. Further, after 8 s of 6.2 W within a 3 mm spot on the lens surface, the light scattering increase in the lens was delayed at least 18 hrs after the exposure.

Keywords: Near, infrared, radiation, cataract, photochemical

1. INTRODUCTION

Vogt argued that infrared radiation (IRR) cataract is the result of direct absorption of IRR in the crystalline lens [1] while Goldmann proposed that IRR cataract is due to heat transferred from the iris [2].

Wolbarsht in experimental exposures with a CW Nd:Yag (1064 nm) laser of rabbit eye [3] has confirmed Goldmanns findings for short exposures where he found a threshold for cataract of approx 0.5 kJ/cm^2 (= 5 MJ/m^2) for exposure times of 25 s that increase to approx. 2 kJ/cm^2 (= 20 MJ/m^2) for exposure times of 90 s. But, for long term low irradiance exposures (Exp time > 90 s, E < 200 kW/m^2 (=20W/cm^2); approx 1 W confined in a 3 mm spot diameter) the threshold remained at approx. 2 kJ/cm^2 (= 20 MJ/m^2) up 1050 s. For the long term low irradiance exposures, Wolbarsht found a direct effect on lens proteins and on lenses in vivo, and no indirect effect via iris heating, indicating a photochemical mechanism in IRR cataract [3-5]. Wolbarsht also found a decrease of α-crystalline and a simultaneous increase of larger molecular weight proteins in lenses that had been exposed to 500 W heat lamp in a temperature controlled incubator [6], again indicating a photochemical effect.

Pitts et al in 1980 presented in vivo rabbit exposure to a wide spectrum Xenon source filtered with a Schott filter so that the output spectrum contained wavelengths between 715-1400 nm, mainly below 1100 nm [7, 8]. They found an in vivo threshold dose for lens damage of on the order of 4 kJ/cm^2 (40 MJ/m^2) with irradiances below 4 kW/m^2 (= 0.4 W/cm^2) (50 times less than that used by Wolbarsht) and an exposure time that exceeded 500 s.

The threshold was only noted when the iris was overlying the lens, strongly indicating a thermal damage. The opacity was an anterior subcapsular opacity. The threshold detected was lower than the threshold dose for corneal damage. They pointed out that they could only find cataract after indirect heating by the iris but their data [7, 8] clearly indicates reciprocity after irradiances below 35 kW/m^2 which were associated with a threshold dose of 40 MJ/m^2.

Vos and Van Norren argued that an irradiance of 1 kW/m^2 would not increase the temperature of the anterior segment more than 1 °C. Based on this, ICNIRP has set the threshold limit to 100 W/m^2 in warm environments [9]. The threshold limit for IRR-A, thus is based on thermal injury only, despite that Wolbarsht claims reciprocity for damage

Ophthalmic Technologies XIX, edited by Fabrice Manns, Per G. Söderberg, Arthur Ho
Proc. of SPIE Vol. 7163, 716311 · © 2009 SPIE
CCC code: 1605-7422/09/$18 · doi: 10.1117/12.816848

after exposure to a 1064 CW Nd:Yag laser [3-5] and after in vitro exposure of the lens to a heat lamp [6], and that Pitts et al. also found support for a photochemical effect of IRR in the lens [7].

Further, the finding that steel and glass workers that were exposed to daily doses of 80-400 mW/cm^2 for 10-15 yrs developed cataract [10] also indicates a photochemical effect, although this could also be due to a slight temperature increase over a very long time.

The cornea transmits considerable amounts of IRR in the wavelength region, 750-1400 nm [11] and a large fraction of this is absorbed in the ocular lens. The current ICNIRP Guidelines for broad band sources [9] are based on a thermal effect only of IRR-A. If there is a photochemical effect of IRR-A in the lens, the ICNIRP Guidlines for broad band sources [9] are incorrect and there is a potential for cumulative effects of IRR over time. It was stated in a recent CIE-document that the recent developments and quickly increasing use of IRR-A LEDs and diode lasers in short distance non contact communication makes it urgent to experimentally clarify if there is a photochemical effect of IRR-A so that safe exposure to these devices can be defined on a sound empirical ground [12].

One of the criteria for differentiation of thermal and photochemical effects is that a thermal effect is instant while a photochemical effect usually expresses a delay between exposure and biological expression of damage.

The purpose of the present study was to determine if damage after just above in vivo threshold dose of IRR-A is instant or occurs with a delay. As a first step, the just above threshold dose was determined by increasing the exposure time at constant irradiance. As a second step the evolution of lens damage was studied after just above in vivo threshold dose.

1 METHODS

1.1 Experimental animal

The experimental animal was 6 weeks old (150 g) albino Sprague-Dawley female rats. The animals were kept and treated according to the ARVO Statement for the Use of the Animals in Ophthalmic and Vision Research. Ethical permission: Stockholms Norra Djurförsöksnämnd.

1.2 Radiation source

A single mode CW fiber laser emitting at 1090 nm (Model SP-120C, SPI Lasers, UK) with a max output power of 120 W was used for exposures. The beam was adjusted to a quasi flat top profile at the cornea, within the diameter of the pupil. The radiation was strongly focused in front of the cornea in order to produce a diverging beam on the cornea, aiming for a slightly converging beam after the crystalline lens (Figure 1).

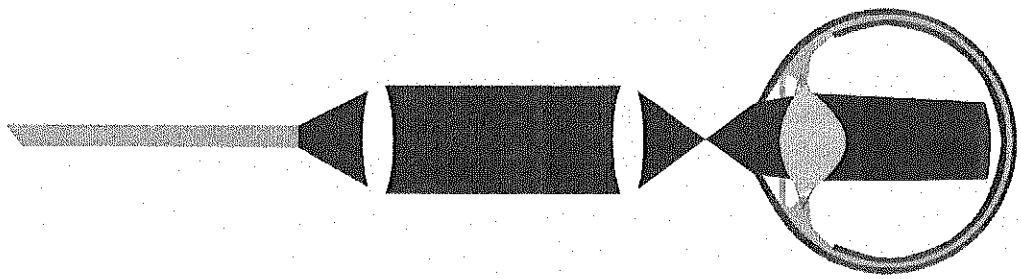

Figure 1 Exposure geometry

This set-up was chosen to spread the transmitted beam as much as possible on the retina, in order to minimize heat build up in the retina during the exposure.

Beam power was measured with a calibrated commercial laser power meter.

1.3 Experimental procedure

At 10 min. prior to exposure, the animal was anesthetized with ketamine 94 mg/kg plus xylazine 14 mg/kg intraperitoneally and 5 min later both pupils were dilated with tropicamide. Then, the animal was exposed to 6.2 W within the pupillary area on one side while the other side was kept as a control eye. After the exposure, the animal was returned to the cage for 1 week. Then, the animal was sacrificed and the lenses were isolated and measured for forward light scattering with the light dissemination meter [13].

1.4 Experimental design

1.4.1 Determination of just above threshold dose

Altogether, 12 animals were divided into four exposure time groups (5, 8, 13 and 20 s) of three animals. For each animal, the light scattering was measured three times in both lenses. Then, the difference of light scattering was calculated between the two eyes.

1.4.2 Determination of time delay between exposure and expression of light scattering in the lens

The exposure time was selected to 8 s based on the first experiment. Then, altogether 16 animals were divided on four post exposure interval groups (6, 18, 55 and 168 hrs after exposure). For each animal the intensity of light scattering was measured three times in both lenses. Then, the difference of light scattering was calculated between the two eyes.

2 RESULTS

2.1 Determination of just above threshold dose

At exposures of 6.2 W IRR-A at 1090 nm quasi-top hat spatial distribution within 3 mm on the lens surface, exposures of 8 s or above were found to cause induced forward light scattering (**Table 1**).

Table 1
Light scattering induced after in vivo exposure to near-infrared radiation at 1090 nm as a function of exposure time

Exp. Time (s)	Difference of forward light scattering between exposed and not exposed contralateral eye	
	$CI_{\mu}(0.95)$ (Rel.)	N
5	0.02 ±0.07	3
8	0.21 ±0.04	3
13	0.34 ±0.02	3
20	0.92 ±0.03	3

For all exposures, 6.2 W quasi-tophat spatial distribution was delivered within 3 mm on the anterior lens surface

2.2 Determination of time delay between exposure and expression of light scattering in the lens

After 8 s of 6.2 W quasi-top hat spatial distribution in vivo exposure to IRR-A at 1090 nm in a 3 mm spot within the pupil, there was a time lag for onset of induced light scattering of more than 18 hrs. The, light scattering then increased gradually, the increase rate declining towards an asymptote (Table 2).

Table 2
Evolution of forward light scattering in the lens after just above threshold dose of in vivo exposure to 1090 nm

Post exposure time (Hrs)	Difference of forward light scattering between exposed and not exposed contralateral eye $CI_{\mu}(0.95)$ (Rel.)	N
6	0.02 ±0.07	4
18	0.05 ±0.09	4
55	0.68 ±0.12	4
168	0.93 ±0.15	4

For all exposures, 8 s of 6.2 W quasi-tophat spatial distribution was delivered within 3 mm on the anterior lens surface

3 DISCUSSION

The purpose of the current study was to determine if close to threshold damage is instant or expresses a time delay after an in vivo exposure to IRR-A.

Despite the fact that the radiation was spread out on the retina, the radiation absorbed in the retina must have induced a temperature increase. It cannot be excluded that the increased retinal temperature, through heat diffusion increased the temperature in the lens. This problem can be reduced if a larger eye is used, e.g. in rabbits. That would however have increased the cost for the experiment in a way that did not seem reasonable at this stage of the project.

The just above threshold dose found in the first part of the current work for 1090 nm, 6.2 W for 8 s within 3 mm = 0.7 kJ/cm^2 (7 MJ/m^2) (Table 1) is slightly lower than, but of the same order as, the threshold previously published by Wolbarsht for extended exposures (>90 s) of 1064 nm, 2 kJ/cm^2 (20 MJ/m^2) [3] and similarly of the same order as that found by Pitts et al. for broad band IRR-A, 4 kJ/cm^2 (40 MJ/m^2) [7].

The finding that there was a time delay of more than 18 hrs between exposure and development of light scattering in the lens (Table 2) is consistent with a photochemical effect of the exposure and contradicts a thermal damage mechanism. It is however possible that an instant temperature increase during the exposure led to denaturation of functional proteins and that it took some time for that damage to become biologically expressed.

The outcome of the current study thus supports the data of Wolbarsht [3] and Pitts et al. [7] indicating a photochemical mechanism for IRR-A. A photochemical mechanism for IRR-A implicates that every photon absorbed by resonance, even at very low intensities, over a long time will cause molecular damage that cumulates. If the cumulated damage reaches a certain threshold level, it would be expected that cataract is expressed. If such a photochemical effect exists, the threshold dose should be constant and exposure time independent. Further, if resonance absorption occurs, the effect should be strongly wavelength dependent.

Considering the quickly increasing use of IRR-A for signal transmission in remote control applications and sensing technology in remote controls, it has become very important to exclude that IRR-A causes photochemical damage. If a photochemical damage mechanism exist for IRR-A, the safety guidelines for avoidance of cataract after exposure to IRR-A have to be changed. Further, it is plausible that it may be possible to select specific wavelengths for signal transmission and sensing that express limited if any photochemical damage in the lens.

4 ACKNOWLEDGMENT

The current study was supported by Swedish Research Council, project K2006-74X-15035-03-2 and K2008-63X-15035-05-2, Swedish Radiation Protection Authority (SSI), Konung Gustav V:s och Drottning Victorias Frimurarstiftelse, Synfrämjandets forskningsfond and Uppsala Läns Landsting's Research grants (ALF).

REFERENCES

1 Vogt. A Fundamental investigations of the biology of infrared. *Klin Monatsbl Augenheilkd* 89, 256-258, 1932

2 Goldmann. H Genesis of cataract. *Arch Ophthalmol* 9, 314. 1933

3 Wolbarsht. M. L Ocular effects of non-ionizing radiation. *SPIE Proceedings* 229, 121-142, 1980

4 M.L. Wolbarsht, M.A. Orr, B.S. Yamanashi, J.S. Zigler and I.B.C. Matheson, *The orgin of cataracts in the lens from infrared laser radiation* In: Ann. Report contract DAMD 17-74-C-4133, US Army Research and Development Command,, Washington, DC, 1977

5 Wolbarsht. M. L Cataract from infrared lasers: evidence for photochemical mechanisms. *Lasers and Light in Ophthalmology* 4, 91-96, 1991

6 M.L. Wolbarsht, In: Safe ocular levels for IR occupational exposure: Final Report, NIOSH 0053-04, NIOSH, 1978

7 D.G. Pitts and A.P. Cullen, *Determination of ocular threshold levels for infrared radiation cataractogenesis* In: NIOSH # 77-0042-7701,, NIOSH, 1980

8 Pitts. D. G and Cullen. A. P Determination of infrared radiation levels for acute ocular cataractogenesis. *Albrecht Von Graefes Arch Klin Exp Ophthalmol* 217, 285-297, 1981

9 ICNIRP Guidelines on limits of exposure to broad-band incoherent optical radiation (0.38-3um). *Health Phys* 73, 539-554, 1997

10 Lydahl. E Infrared radiation and cataract. Thesis. *Acta Ophthalmol (Copenh)* Suppl 166, 1984

11 Boettner. E. A and Wolter. J. R Transmission of ocular media. *Invest Ophthalmol Vis Sci* 1, 776-783, 1962

12 D.H. Sliney, *Need for experimental research study of infrared cataract* In: CIE Division 6: Photobiology and Photochemistry report,, CIE, Geneva, 2006

13 Söderberg. P. G, Chen. E and Lindström. B An objective and rapid method for the determination of light dissemination in the lens. *Acta Ophthalmol (Copenh)* 68, 44-52, 1990

*per.soderberg@ophthalmology.neuro.uu.se; +46 18 611 9990; Fax +46 18 50 48 57;
http://www.ste.ki.se/oph/research_projects/Peso/;
Dept. of Neuroscience, Ophthalmology, Uppsala University, Akademiska sjukhuset, SE-751 85 UPPSALA, SWEDEN.
NF: No financial interest.