Nicole Sieber*, Philipp Kölbl, Christian Lingenfelder, Kathrin Stucke-Straub, Sebastian Kupferschmid and Martin Hessling

Measurement of the retinal irradiation exposure during diaphanoscopic illumination

Abstract: For the visualisation of the intraocular space it is essential to illuminate the inside of the eye. One illumination approach is diaphanoscopy, in which the light of an extraocular source is transmitted through the tissue layers of the eyewall. The transmission properties of these tissues and their irradiation load depend on applied diaphanoscope contact pressure. However, excessive illumination can lead to irreversible photochemical and thermal damage to the retina. In diaphanoscopic illumination, the retina is particularly at risk due to its proximity to the light source. Therefore, the photochemical and thermal retinal hazards, resulting from direct transmitted light through the eyewall, are determined for different applied pressures of the diaphanoscope on the eye (15, 65 and 115 kPa). The study is performed on porcine eyes with different pigmentation. So, the difference in intraocular irradiance, photochemical and thermal hazards, as well as the maximal exposure time is also examined for different pigmentations. For less pigmented eyes the irradiance inside the eye, the photochemical and the thermal hazard are higher than for higher pigmented eyes. The values also become significantly higher for increasing applied pressure with the diaphanoscope but do not exceed given limits in the standard DIN EN ISO 15004-2: 2014.

Keywords: Intraocular illumination, Pigmentation, Retina, Exposure time, Thermal hazard, Photochemical hazard

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*Corresponding author: **Nicole Sieber**, Institute of Medical Engineering and Mechatronics, Ulm University of Applied Sciences, Albert-Einstein-Allee 55, 89081 Ulm, Germany, e-mail: Nicole.Sieber@thu.de

Phillip Kölbl, Institute of Medical Engineering and Mechatronics, Ulm University of Applied Sciences, Ulm, Germany

Christian Lingenfelder, Pharmpur GmbH, Koenigsbrunn, Germany

Kathrin Stucke-Straub, Department of Mathematics, Natural and Economic Sciences, Ulm University of Applied Sciences, Ulm, Germany

Sebastian Kupferschmid, Clinic of Ophthalmology, Bundeswehrkrankenhaus, Ulm, Germany

Martin Hessling, Institute of Medical Engineering and Mechatronics, Ulm University of Applied Sciences, Ulm, Germany

1 Introduction

For direct intraocular illumination of the retina during diagnostic procedures, a sufficient bright illumination of the intraocular space is required. Therefore, diaphanoscopic illuminations are a commonly used technique in ophthalmology, which allows to enlighten the intraocular space without surgical incisions. A fiber connected to a light source is in contact with the sclera and illuminates the intraocular space by transmitting light through the eyewall (see figure 1). This makes the intraocular space visible to the surgeon when he looks into the eye via the cornea and the lens. Beneath visualizing the vitreous tissue [1-3], transillumination is also applied for localization of tumors [4] and cyclodialysis clefts [5] in the eye. However, excessive irradiance can cause irreversible photochemical and thermal damage to the retina. In the international standard DIN EN ISO 15004-2: 2014 [6] limit values for the irradiance of the retina are given, which must not be exceeded. In this work, the retinal irradiances and occurring hazards during diaphanoscopic illumination through the porcine eyewall, resulting from direct transmitted light, are measured and assessed for different pressures on the eye. Because of their similarity in physiology and anatomy, porcine eyes are a good alternative to human eyes [7] and are therefore employed in this study.

Figure 1: Schematic view of diaphanoscopy. The sketch of the eye is adapted from [8]. The diaphanoscopic fiber is in contact with the sclera and illuminates the intraocular space with the light that is transmitted through the eyewall.

2 Materials and Methods

By applying pressure onto the eye, the transmission of the eyewall rises [9, 10]. In this application, the intraocular brightness is also expected to rise. The intraocular irradiance can be calculated with eq 1, where E_λ is the spectral irradiance and $\Delta\lambda$ is the sum interval. It is known that blue and UV light pose a photochemical hazard to the retina [11-13]. To determine this photochemical hazard during diaphanosopic illumination the photochemical weighting function $A(\lambda)$ has to be considered (see figure 2 and eq 2) [6]. $A(\lambda)$ describes the efficacy with which short-wavelength visible light can generate damage to the human retina. In order to prevent photochemical damage a maximum value of 10 J/cm² is given in DIN EN ISO 15004-2: 2014. With this limit value the maximal exposure time t_{max} can be determined (see eq 3). For calculating the thermal hazard, due to heating of the retina, $A(\lambda)$ is replaced by the thermal hazard weighting function $R(\lambda)$ (see figure 2 and eq 4) [6].

$$E = \sum_{350\text{ nm}}^{1150\text{ nm}} E_\lambda \cdot \Delta\lambda \quad (1)$$

$$E_{A-R} = \sum_{305\text{ nm}}^{700\text{ nm}} E_\lambda \cdot A(\lambda) \cdot \Delta\lambda \quad (2)$$

$$t_{max} = \frac{10 \frac{\text{J}}{\text{cm}^2}}{E_{A-R}} \quad (3)$$

$$E_{VIS-R} = \sum_{380\text{ nm}}^{1400\text{ nm}} E_\lambda \cdot R(\lambda) \cdot \Delta\lambda \quad (4)$$

Figure 2: Photochemical hazard weighting function $A(\lambda)$ (blue) and thermal hazard weighting function $R(\lambda)$ (orange) according to DIN EN ISO 15004-2: 2014 [6].

Using the illumination system Accurus 600DS of Alcon Laboratories, which contains a halogen lamp in combination with a standard endoillumination fiber with a diameter of 23 gauge of D.O.R.C (REF 3269.B06) for diaphanosopic illumination leads to an output of the fiber of $E = 118 \text{ mW/cm}^2$. The diameter of the diaphanosopic fiber tip is 1.6 mm. This would lead to a weighted retinal irradiance of $E_{A-R} = 18162 \text{ } \mu\text{W/cm}^2$. This would exceed the limit of $E_{A-R} = 440 \text{ } \mu\text{W/cm}^2$ given in DIN EN ISO 15004-2: 2014 [6]. If this limit is

exceeded the maximal exposure time t_{max} should be determined and respected. After transmission through the eyewall, directly behind the position where the diaphanoscope is in contact with the eye, it is $E_{A-R} = 19.25 \text{ } \mu\text{W/cm}^2$. Therefore, the intraocular irradiance inside the eye and its increase for higher applied pressure with the diaphanoscope on the eye has to be investigated. During diaphanoscopy, light is transmitted through the sclera and choroid, which leads to a reduction of the intensity reaching the retina. However, their transmission properties are pressure dependent [9]. With increasing pressure, the transmission of the eyewall rises. Therefore, it is assumed that the intraocular irradiance will also increase and that the limit values for E_{A-R} and E_{VIS-R} may be exceeded. In order to prove this increase, a pressure inducing setup, illustrated in figure 3, is created. The pressure dependency is investigated for a total number of $N = 142$ porcine eyes and different applied pressures of 15, 65 and 115 kPa to the eye (74, 34 and 34 eyes, respectively). These pressures correspond to an intraocular pressure rise of $\Delta\text{IOP} = 23, 78$ and 132 mmHg , which are common values during eye surgery. The detecting fiber (NA = 0.39) is inserted in the eye on the opposite of the illumination and detects direct transmitted light inside of the eye. The pressure-inducing tip consists of an emitter fiber, which combines the light of a xenon and a halogen lamp with a total spectral range of 350 - 1150 nm, which are the most common illumination sources types for

Figure 3: A: Scheme of the measurement setup to determine the pressure dependent intraocular irradiance resulting from direct transmitted light. B: Photograph of the real measurement system.

ophthalmological instruments. A pressure sensor filled with BSS (Balanced Salt Solution) provides the pressure value in the anterior chamber of the eye. An adjustable bar is used to decrease the distance between the emitter and detector fiber. The porcine eye is located between those two fibers. Therefore, with decreasing distance between those fibers, the eye is compressed and so the intraocular pressure increases.

3 Results

3.1 Direct intraocular irradiance depending on the applied pressure

With increasing applied pressure on the eye, the direct intraocular irradiance E increases (see figure 4A, yellow bars). Therefore, the thermal and photochemical hazard also increase for higher pressures (see figure 4B and C, yellow bars) and the maximum exposure time decreases (see figure 4D, yellow bars). The limit values on the retina of $440 \mu\text{W}/\text{cm}^2$ for E_{A-R} and $0.7 \text{ W}/\text{cm}^2$ for E_{VIS-R} [6] are not exceeded.

Figure 4: The direct intraocular irradiance E rises with higher applied pressure (A) as well E_{VIS-R} (B) and E_{A-R} (C). The maximal exposure time $t_{\max}$ decreases for increasing pressure (D). The limit values $440 \mu\text{W}/\text{cm}^2$ for E_{A-R} and $0.7 \text{ W}/\text{cm}^2$ for E_{VIS-R} (DIN EN ISO 15004-2: 2014 [6]) are not exceeded. For 15 and 65 kPa the intraocular irradiance is higher for higher pigmented eyes (orange bars) than for less pigmented eyes (blue bars). The yellow bars are the results from blue and brown eyes together.

To determine whether the pressure has a significant influence on E_{A-R} and E_{VIS-R} a statistical analysis was performed with SPSS Statistics. Due to the lack of variance homogeneity of the data an univariate Welch-ANOVA was performed. The results show significant differences ($p < 0.05$) in E , E_{A-R} and E_{VIS-R} for different pressures of 15, 65 and 115 kPa, where the p -values are adjusted with the Bonferroni correction. The corresponding values for E , E_{A-R} and E_{VIS-R} for different pressures are listed in table 1. The fraction $X(p)/X(15 \text{ kPa})$ is shown in figure 5, where $X(p)$ denotes the parameter E , E_{A-R} , $t_{\max}$ and E_{VIS-R} for a given pressure and $X(15 \text{ kPa})$ is the value for these parameters at 15 kPa. By applying pressure with the diaphanoscope on the eye the retinal irradiance

Figure 5: The direct intraocular irradiance E (blue), E_{VIS-R} (violet) and E_{A-R} (orange) rises for higher applied pressure. The maximal exposure time $t_{\max}$ (yellow) decreases for increasing pressure.

weighted with the thermal hazard increases by a factor of 1.97 for 115 kPa and the one weighted with the photochemical hazard even by a factor of 2.14. This leads to a reduction of the maximum exposure time of 53%.

3.2 Direct intraocular irradiance depending on the pigmentation of the eye

The examination of the influence of pigmentation on the direct intraocular irradiance revealed that for 15 and 65 kPa the irradiance is higher for less pigmented eyes (blue eyes) than for more pigmented eyes (brown eyes) (see blue and orange bars in figure 4A), as well as for E_{A-R} and E_{VIS-R} (see blue and orange bars in figure 4B and C). To investigate the influence of the pigmentation of the eye on the intraocular irradiance a WELCH-test was performed in SPSS, due to missing variance homogeneity of the data. For 15 kPa E , E_{A-R} and E_{VIS-R} for blue and brown eyes differ significantly from each other. For the higher pressure 65 kPa only E_{A-R} show significant differences and for 115 kPa a significant difference between blue and brown eyes cannot be observed. The values for E , E_{A-R} and E_{VIS-R} for different pigmentation are given in table 1.

Table 1: Calculated mean values and standard deviation for the direct intraocular irradiance E and the retinal weighted irradiances E_{A-R} and E_{VIS-R} for different applied pressures p , for lower pigmented eyes (blue), higher pigmented eyes (brown) and all eyes together (all).

eyes	p [kPa]	E [$\mu\text{W}/\text{cm}^2$]	E_{A-R} [$\mu\text{W}/\text{cm}^2$]	E_{VIS-R} [$\mu\text{W}/\text{cm}^2$]
all	15	66.76 ± 23.96	0.25 ± 0.14	23.85 ± 8.63
	65	104.22 ± 46.30	0.37 ± 0.25	36.45 ± 16.27
	115	129.79 ± 33.31	0.53 ± 0.31	46.88 ± 13.66
brown	15	63.37 ± 22.92	0.21 ± 0.11	22.23 ± 7.92
	65	100.55 ± 48.46	0.30 ± 0.20	34.29 ± 16.65

eyes	p [kPa]	E [μW/cm²]	E _{A-R} [μW/cm²]	E _{VIS-R} [μW/cm²]
blue	115	129.93 ± 36.64	0.54 ± 0.35	47.18 ± 15.36
	15	81.30 ± 23.64	0.40 ± 0.15	30.77 ± 8.38
	65	116.14 ± 38.80	0.61 ± 0.25	43.56 ± 13.52
	115	129.37 ± 20.92	0.48 ± 0.12	45.92 ± 6.02

4 Conclusion and Outlook

The presented data reveals that the pressure with which the diaphanoscope is pressed onto the eye plays an important role for the direct intraocular irradiance. Diaphanosopic illumination can pose relevant stress on the retina as certain irradiation times are exceeded. The pigmentation of the eye also has an influence on the photochemical and thermal hazard on the retina during diaphanosopic illumination. These investigations were performed on porcine eyes but a similar behaviour is also expected for human eyes. Therefore, this is an important fact the surgeon should be aware of during eye surgery. Due to the light attenuation by pigmentation it is assumed that a stronger light source would be needed for diaphanosopic illumination of human eyes in case of higher pigmentation.

Using this measurement setup, the irradiance, which came into the intraocular space by direct transmitted light, can be calculated. Scattered light is not considered here. The focus in this study is on the increase in intraocular irradiance by applying pressure onto the eye. The resulted values for E_{A-R} and E_{VIS-R} are very small in comparison to the limit values in the standard. The proportion of scattered light may further increase these values. For further investigations, replacing the detection fiber with a wide-angle fiber, nearly all light, including the scattered and reflected light, could be detected inside the eye. This would allow the measurement of the total intraocular irradiance as well as the photochemical and thermal hazard.

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