Importance of Light Filters in Modern Vitreoretinal Surgery: An Update of the Literature

Michele Coppola^a Maria Vittoria Cicinelli^b Alessandro Rabiolo^b
Giuseppe Querques^b Francesco Bandello^b

^aDepartment of Ophthalmology, ASST Monza, Monza, and ^bDepartment of Ophthalmology, University Vita-Salute, Scientific Institute San Raffaele, Milan, Italy

Keywords

Endoillumination · Light filters · Phototoxicity · Vitreoretinal surgery

Abstract

Purpose: Direct endobulbar illumination during vitreoretinal surgery causes light-induced retinal damage known as phototoxicity. Spectral filters have been proposed to eliminate hazardous wavelengths from the emission spectrum before entering the eye. The purpose of our paper is to review advances in vitreoretinal surgery, focusing on intraoperative light filters. **Methods:** A PubMed and Medline database search was carried out using the terms “spectral filters” associated with “vitreoretinal surgery,” “phototoxicity,” and “vitrectomy.” Original articles, reviews, and book chapters up to March 2017 were reviewed; a few select articles published before 2000 are included for historical purposes. Material from recent meeting presentations was also added. The preferred language for the reviewed literature was English. **Results:** Spectral filters significantly reduce the risk of phototoxicity associated with endoillumination in vitreoretinal surgery, allowing higher exposure times than with optic light fibers alone. Spectral filters may affect intraoperative

luminance, but do not alter color contrast. Amber filters showed superiority over green and yellow filters. **Conclusion:** The choice of light sources coupled to spectral filters is strongly suggested, especially in dye-assisted chromovitrectomy. Histological donor eye studies and large multicenter trials are needed to validate the amount of photoprotection provided by spectral filters before a general recommendation can be made.

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Introduction

Pars plana vitrectomy was first introduced by Robert Machemer with contributions from Thomas M. Aaberg, who invented a single-port, multifunctional 17-gauge cutter, the vitreous infusion suction cutter. Pars plana vitrectomy allowed for the first time the removal of vitreous through a closed system, rather than through an open-sky technique [1]. Since then, there have been innumerable advances in vitreoretinal surgery; significant improvements have occurred not only with vitrectomy probes, but also in other surgical technical aspects including fluidics, instrumentation, viewing systems, wound con-

struction, and endoillumination [2]. Illumination of the retina and the vitreous cavity during surgery is accomplished by a fiber optic light source inserted in a light pipe or chandelier. Since 1982, it is well known that direct endobulbar illumination may cause light-induced retinal damage known as phototoxicity [3, 4]. The latest advancements have focused on increasing endoillumination safety by changing the light source, adding light filters, and increasing the working distance, as well as gaining an understanding of the potential interactions between light and vital dyes commonly used in vitreoretinal surgery. However, only a few clinical studies have aimed to objectify the advantages of spectral light filters on intraoperative light-related risk.

The purpose of this paper is to review some advances in vitrectomy technology focusing on intraoperative light filters.

Phototoxicity

The exposure of the macula to high-intensity light beams during posterior segment surgery makes neural and retinal pigment epithelium cells highly susceptible to phototoxicity [3, 4]. Light-induced damage takes place through 3 different mechanisms: photomechanical, photothermal, or photochemical. Photomechanical damage occurs when intense pulsed laser radiation produces vaporization, fragmentation, or disruption of retinal tissue. Thermal injury appears when the tissue temperature is raised more than 10°C above usual, leading to protein denaturation, loss of tertiary structure of macromolecules, and fluidization of cell membranes. Photochemical harm occurs when high photon energies break molecular chemical bonds, causing free radical formation and increasing the levels of oxidative stress.

Retinal damage is cumulative and is related to power, duration of exposure, and proximity of the light source, especially with short wavelength (400–500 nm) and ultraviolet light rays (<400 nm) [5]. Another important concept for understanding phototoxicity in endoillumination is the brightness, i.e., the intensity of a light source expressed in lumens. High-intensity endoillumination is associated with increased risk of retinal photodamage.

Cases of intraoperative iatrogenic retinal injury have been rarely described, but they can potentially result in permanent visual dysfunction, especially in patients affected by retinal degeneration [6]. While anterior segment surgery is unlikely to be associated with iatrogenic photic maculopathy, vitreoretinal surgery, with the lack

of natural filtering from anterior ocular structures, direct foveal illumination, and increased proximity of the light source, may seriously carry the risk of foveal phototoxicity [7, 8].

The ISO 15004-2 Ophthalmic Instruments – Fundamental Requirements and Test Methods, Part 2: Light Hazard Protection (ISO 2007) is a comprehensive standard that lists exposure limits for all known light hazards to the eye [9]. One of the most important parameters to take into consideration is the aphakic hazard sum, which is the standard measure of light source safety and can be expressed as the intersection between the output of a light source with the aphakic hazard curve defined by Ham et al. [10] in their study on aphakic rhesus monkeys. They calculated the aphakic hazard curve for different wavelengths and demonstrated an increased risk of toxicity occurring after UV/blue spectrum exposure. The aphakic hazard sum can be inversely expressed as the number of lumens that are necessary to create a watt of hazard (lumens/hazard watt); the higher the lumens necessary to create a watt of hazard, the safer the light source. Another factor of great importance is the retinal threshold time, which incorporates not just the inherent safety of the light source (aphakic hazard sum), but also the working distance, brightness, cone of illumination used (numerical aperture of the fiber), and industry standard for toxicity of 25 J/cm². Methods for calculation of the potential optical radiation hazards from various ophthalmic instruments have been described elsewhere [11].

Phototoxicity and Chromovitrectomy

Light-related retinal damage may be enhanced by the injection of vital dyes or crystals during vitreoretinal surgery (chromovitrectomy). These dyes are used to stain different intraocular structures, such as the internal limiting membrane (ILM), vitreous, and epiretinal membrane, and to facilitate their identification and surgical removal [12]. Different vital dyes have been tested for chromovitrectomy, including trypan blue, patent blue, triamcinolone acetate, indocyanine green, sodium fluorescein, and brilliant blue (BBG). The ideal dye should have high affinity for ocular tissues and limited toxicity. At first, indocyanine green-guided chromovitrectomy gained high worldwide popularity, making ILM peeling easier and less traumatic in both macular hole and pucker removal surgery [13]. However, subsequent evidences showed the potential harmful effect of indocyanine green on ocular structures, including postsurgical retinal pigment epithe-

Table 1. Endoillumination distance and threshold times

Light source	Working distance 4 mm	Working distance 8 mm
Alcon Accurus Halogen 20g light pipe High 3	13 min 2 s	43 min 32 s
B&L Millennium Metal Halide 20g light pipe on Max	6 min 44 s	22 min 28 s
DORC Hexon Metal Halide 20g light pipe on Max	7 min 13 s	27 min 1 s
Synergetics Xenon 20g light pipe Max	9 min 14 s	30 min 50 s
Synergetics Xenon 25g Awh Chandelier on Max		4 h 17 min 39 s

lium alterations, visual field defects, and optic nerve atrophy [14]. In contrast, BBG features one of the lowest toxic profiles and has been proven to reduce the rate of neural cell apoptosis [15].

Besides the specific risk related to each single molecule, vital dyes may interact with light sources and induce photosensitization of the tissue staining by an overlap of the emission spectrum of the light source and the absorption band of the vital dye used during vitrectomy. This interaction could have an additive effect in the increase of oxidative stress levels, release of free radicals, and retinal or retinal pigment epithelium damage [16].

Light Sources

The first 20-G light probes used in vitreoretinal surgery relied on halogen/metal halide light sources, with a power output of around 8 lumens. With the development of modern small-gauge vitrectomy, new stronger xenon sources have been introduced, coupled with chandelier, illuminated laser probes, and vitrectomy picks. Theoretically, the short wavelength light emitted by these xenon lamps would increase the overall rate of photochemical damage. The use of chandeliers, which illuminate from a greater distance than conventional light sources, would significantly reduce this risk. For instance, modifying the working distance of the light probe from 4 to 8 mm from the retina increases the retinal threshold time more than 3-fold (Table 1). In addition to improved surgical safety, chandeliers free up a surgeon's hand from holding a light probe, thus allowing true bimanual manipulation during surgery.

To obtain a more powerful illumination source, a mercury vapor illuminator (Photon II; Synergetics) has been recently developed. This instrument features a dual-output pathway from one mercury vapor bulb, with spherical reflectors adapted to generate homogenized illumination and sharpen the focus light spot. The luminous efficacy

of the mercury vapor illuminator reaches 402 lm/W of optical power, which is brighter than any commercially available xenon light illuminator (range: 277–355 lm/W). Moreover, the actual output level of the mercury vapor light can be enhanced to 56 lm through a 25-G optic fiber, which is approximately twice as bright as that of the xenon light source (only 29 lm through the same optic fiber) [17].

The introduction of LED (light-emitting diode) light sources coupled with smaller gauge instrumentation (27-G) would potentially allow a further reduction of the total amount of retinal light exposure.

Recently, the advent of 3-dimensional (3-D) heads-up vitreoretinal surgery offers a potential solution to the phototoxicity issue by enabling digital amplification of camera signals, and thus requiring relatively low endoillumination parameters [18].

Eckardt and Paulo [19] performed 3-D heads-up vitrectomies with digital amplification using 15% less light exposure compared with standard surgery in a small subset of patients. Similarly, Adam et al. [18] found that in 9 out of 10 cases (five 23-G, one 25-G, and three 27-G), the surgeon felt comfortable at an endoillumination level of 10% with an associated average of 14.3 ± 9.5 lux emitted from the 3-D heads-up display surgical platform. In the remaining case (27-G), the operating surgeon felt comfortable at a 3% endoillumination level with a corresponding heads-up display emittance of 15 lux.

Filters

Spectral filters, also referred to as pass filters, have been proposed to eliminate particularly hazardous wavelengths from the emission spectrum before entering the eye through the fiber optic system [20]. The protective effect of spectral filters can also be expressed as an increment in exposure times necessary to reach the predefined ISO 15004-2 (2007) safety limit.

Table 2. Retinal threshold time depending on the filter choice

Unit/filter	ISO value, 10-lm output	Threshold time, 10-lm output	100% output, lm
BrightStar 420, nm	0.7	11 min 54 s	45
BrightStar 435, nm	0.55	15 min 9 s	45
BrightStar 475, nm	0.16	52 min 4 s	44.6
BrightStar 515, nm	0.017	8 h 10 min 12 s	37.8

Many modern endoillumination devices feature a variety of built-in pass filters: the Stellaris PC Surgical Platform (Bausch & Lomb™ Surgical, Aliso Viejo, CA, USA, with green-tin, yellow-tin, and amber filters), the Brightstar Illumination System (D.O.R.C. Dutch Ophthalmic Research Center International B.V., Zuidland, the Netherlands; cutoffs at 435, 475, 515 nm), and the Synergetics Photon 1 and 2 (Synergetics Inc., O'Fallon, MO, USA; cutoffs at 485 nm) – all have incorporated some variant of a yellow filter to screen lower wavelengths (Table 2). Moreover, the mercury vapor illuminator system incorporates a 435-nm cutoff filter to reduce exposure to ultraviolet and blue light spectrum. After passing through the filter, the output of the mercury vapor illuminator has only 2 spectral peaks at 550 and 580 nm (green-yellow), and the entire spectral output curve is mostly confined within the photopic spectral range. The hazard efficacy, which represents the magnitude of theoretical phototoxicity, results in 2,200 lm/hazard W, which is much higher than the hazard efficacy measured in a xenon or halogen light source (range: 1,150–1,900 lm/hazard W).

Little evidence has been published about the possible interference between filters and the surgeon's intraoperative view. A worldwide multicenter study involving 24 surgeons evaluated the effect of different light sources and light filters on tissue visualization during pars plana vitrectomy (359 cases). The baseline xenon light source on the Bausch and Lomb Stellaris PC was compared to the mercury vapor light source and to the xenon light source itself coupled with yellow, green, or amber filters. The evaluation was performed during core vitrectomy, peripheral vitreous base work, macular work, and air-fluid exchange, and the surgeons' impressions were recorded online in a grading system. During all stages of vitreoretinal surgery, the xenon light source, mercury vapor light source, and xenon with yellow and green filters were found to “meet or exceed expectations” in >80% of the cases. The xenon with amber filter had a skewed response with about 50% of surgeons preferring this view and the other 50% hating it [21].

One of the most important limitations concerning the use of a filter is lack of luminance and loss of color contrast. For instance, luminance has been described to drop to 14–71% through a pass filter with a cutoff at 500 nm in a preclinical study, although illumination was still considered sufficient for successful ILM removal [22]. Recently, a preclinical study on postmortem porcine eyes showed that the use of a pass filter, which eliminates all wavelengths shorter than 500 nm during BBG chromovitrectomy, enhanced contrast between the stained ILM and unstained retina [23]. In a prospective observational clinical study on 59 consecutive BBG chromovitrectomy interventions for macular holes, macular pucker, or vitreomacular traction syndrome, 6 different illumination modes were compared consecutively: mercury vapor, mercury vapor/xenon, and xenon followed by xenon combined with an amber, green, or yellow spectral filter. Head-to-head comparison showed a significant advantage for the amber over the green and yellow filters with respect to elimination of short wavelengths and contrast generation. The resulting reduction in light toxicity allowed exposure times more than 3 times higher than with white xenon light alone. The protective effects were less pronounced for the yellow filter and even less for the green filter [24]. Our personal experience on 23-G vitrectomies using an amber filter confirm these data; we compared 5 eyes of 5 patients who underwent vitrectomy for epiretinal membrane peeling using xenon light with an amber filter with 5 cases who underwent surgery without a filter, and found no differences in terms of functional and anatomical improvement and no difficulties perceived by the surgeon in using amber filters [25].

Conclusion

With the advent of modern systems of endoillumination, phototoxicity has become a relevant issue in vitreoretinal surgery. In the context of the data published so far and presented in this review, light toxicity should always

be taken into consideration. The choice of light sources coupled to spectral filters is strongly suggested, especially in dye-assisted chromovitrectomy, as they do not alter the global luminance output during surgery and enhance color contrast. Histological donor eye studies and large multicenter trials are needed to validate the amount of photoprotection provided by spectral filters before a general recommendation can be made.

Disclosure Statement

The authors have no proprietary, funding, or conflicts of interest to disclose.

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