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Positive and negative dysphotopsias in patients with the posterior chamber intraocular lens implanted after cataract surgery

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Modern technologies of examining cataract patients and phacoemulsification with implantation of the posterior chamber intraocular lens (IOL) commonly allow achieving the desired anatomical outcome and a high functional outcome after surgery. The development of postoperative dysphotopsias in patients with a posterior chamber IOL, however, requires a separate consideration. Dysphotopsia can develop practically in any eye with the IOL after cataract surgery and in some cases can affect postoperative vision, which hinders the patient from resuming working life as usual. Clear systemic guidelines for preventing postoperative dysphotopsia are still to be developed.

Introduction

Modern technologies of examining cataract patients and phacoemulsification with implantation of the posterior chamber intraocular lens (IOL) commonly allow achieving the desired anatomical outcome and a high visual outcome after surgery. Nevertheless, various abnormalities can occur in the eye with the IOL after cataract surgery. These include refractive errors (at a rate as high as 10%), corneal dystrophy (1–2%), IOL dislocation (0.2–3.0%), secondary cataract (10–30%), secondary glaucoma (<1%), cystoids macular edema (0–2.35%), retinal detachment (0–3.6%) and endophthalmitis (0.033%) [1–5]. Of note are rates of dysphotopsias (9% to 70%) which occur after cataract surgery with the implantation of an IOL. 41% of patients with a multifocal IOL reported photic phenomena that had not been noticed before cataract surgery. According to Henderson and Geneva, the incidence of positive dysphotopsia in the immediate postoperative period can be as high as 49% but decreases to 0.2% to 2.2% over the following 12 months depending on the IOL type and other factors. The incidence of negative dysphotopsia is up to 15% in cataract surgery patients [6, 7].

The reports on the causes and mechanisms of postoperative dysphotopsias are contradictory and require systematization.

The aforementioned complications occur rarely and are noted in certain groups of patients. For example, a secondary cataract develops almost exclusively after phacoemulsification of a pediatric congenital cataract, retinal detachment most commonly develops after phacoemulsification in highly myopic patients with retinal comorbidity (diabetic retinopathy, age-related macular degeneration, or peripheral retinal degeneration), whereas refractive errors most commonly occur after phacoemulsification in patients with a history of corneal refractive surgery [1, 8, 9].

The development of postoperative dysphotopsias in patients with a posterior chamber IOL requires a separate consideration. This is due to the fact that dysphotopsia can develop practically in any eye with the IOL after cataract surgery and in some cases can affect postoperative vision, which hinders the patient from resuming working life as usual [10].

The purpose of the study was to review the causes and mechanisms of postoperative negative dysphotopsias and methods of their prevention.

Terminology

The term “photopsia” comes from the Greek words photizein (to give light, to illuminate) and opsis (seeing). It is used to denote a group of simple or geometric visual hallucinations. It describes the perception of light arising without an external light stimulus. Photopsias may appear as sparks, flashes, light lines, rings, spots, zigzag lines, lightning bolts, or flickering lights, and are due to inadequate stimulation of retinal photoreceptors and other portions of the visual system. They can develop as a result of physiological processes (e.g., in the presence of increased illumination) or pathological changes (e.g. retinal or optic nerve disorders) in the eye. Photopsias can be caused by abnormal circulation in the retina and other portions of the visual system [11].

The term “dysphotopsia” is used to describe a variety of unwanted visual phenomena encountered by pseudophakic patients, particularly glare and halo. Dysphotopsias develop due to the presence of cataract or IOL on the optic pathway (Leyland and Zinicola, 2003; Wilkins and colleagues, 2013) [12, 13]. These photic phenomena have been referred as edge glare, photic phenomena, undersired light images, or pseudophakic dysphotopsia [14].

Häring and colleagues [7] defined several photopic phenomena. A halo of light is a circle or nearly complete circle of light, usually seen in darkness or dim lighting around a point source of light. Glare is reduced sharpness of vision in bright lights. A curved streak of light is an arc or semicircle of light, usually seen in darkness or dim lighting and lasting only seconds. A flare of light is a streak or "tail" of light that consistently proceeds from the same area and goes in the same direction whenever a point source of light is viewed. A flash of light is a very brief spot, splash or streak of light that may move and does not seem to come from looking at a point source of light. Postoperative dysphotopsias can be divided into two broad categories: positive dysphotopsias and negative dysphotopsias. Positive dysphotopsia stems from addition of light that produces artifacts projected onto the retina that patients may describe as glare, arcs, streaks, rings and halos. Patients describe negative dysphotopsia as shadows, dark spots, or crescents typically perceived in the temporal visual field and arising from the absence of light. Negative dysphotopsias are less common than positive dysphotopsia, affecting about 15% of patients after cataract surgery and persisting in only 2–3% of patients [6].

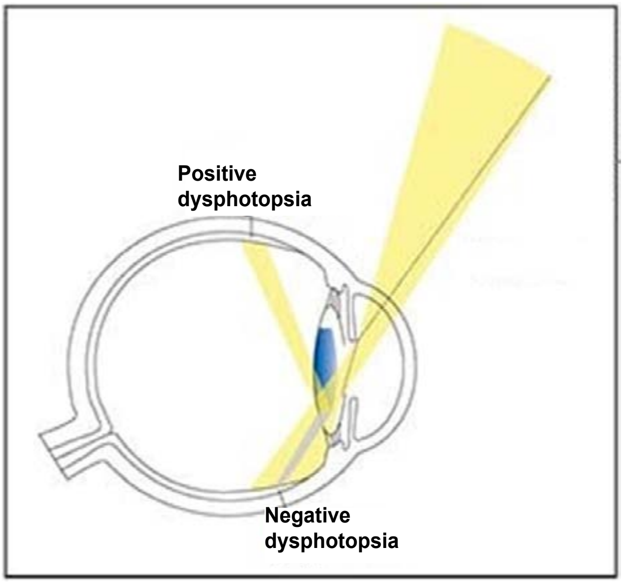

Fig. 1. The light entering the eye from the temporal field of vision crosses the pupil and encounters the flat edge of a high-index-of refraction intraocular lens. Some of the light bounces off the edge, creating one of the positive dysphotopsias [10].

Mechanisms underpinning positive dysphotopsia

1. Numerous studies have compared the incidence of dysphotopsia after the implantation of a multifocal IOL (MIOL) and a monofocal IOL. Irrespective of the type of MIOL, dysphotopsia was experienced significantly more often by patients who had refractive MIOLs than by those who had monofocal IOLs. Researchers believe that this can be explained by the following fact: in the multifocal lens, the available light is splitted into two arms, with both in-focus and out-of-focus images simultaneously presented to the retina due to light aberrations and light diffusion [7]. A dispersion of the energy of the light entering into the eye is especially apparent in the eye with an implanted diffractive multifocal IOL [15]. Alba-Bueno and colleagues [16] aimed to present the theoretical and experimental characterization of the halo in MIOL. They made a comparison between the halos induced by different MIOL of the same base power (20D) in an optical bench. As predicted by theory, the larger the addition of the MIOL, the larger the halo diameter. In the case of a trifocal-diffractive IOL the most noticeable characteristic is the double-halo formation due to the 2 non-focused powers [16].

A newly developed extended-depth-of-focus IOL, which has a wavefront-shaped anterior surface, has shown a promising outcome in minimizing dysphotopsia, the biggest issue after diffractive type IOL implantation [17, 18].

2. Reflection of light from the posterior surface of an IOL with a high index of refraction (1.55) and a radius of curvature of 32 mm. Erie and colleagues assessed the potential for reflected glare images from commonly used IOL materials and designs. The interaction of reflected light rays from 3 commonly used IOLs with different optic designs (equi-biconvex: 10.0 and 15.0 mm anterior radius of curvature; unequal biconvex: 32.0 mm anterior radius of curvature) and optic materials (silicone, poly[methyl methacrylate], and acrylic) were examined in an eye model. The unequal biconvex design concentrated reflected light on a retinal area that was 60-fold smaller than that of the equi-biconvex design. Increasing the refractive index of the IOL material from 1.43 (silicone) to 1.55 (acrylic) increased the amount of reflected light 5-fold. The authors concluded that an unequal biconvex IOL design (32.0 mm anterior radius of curvature) composed of a higher refractive index material increased the potential for postoperative glare and external reflections.

3. A squared-edge design is an IOL property contributing to positive dysphotopsias. Positive dysphotopsia has been reported to occur in eyes with a square-edge IOL but not in eyes with a round-edge IOL. Exchanging the AcrySof IOLs with silicone IOLs alleviated most symptoms [10]. The figure below (drawn by Kevin Miller [19]) shows a scheme for dispersion of light in the eye with a square-edge IOL made of high refractive index material.

4. Pupillary width has an effect on positive dysphotopsia due to recruitment of more zones of diffraction. Dilating the pupil makes the symptoms of positive dysphotopsia better, but, unfortunately, dilation can induce glare and nighttime difficulties [19].

Mechanisms underpinning negative dysphotopsia

1. Negative dysphotopsia incidence and severity depend on the material of IOL and its properties such as the index of refraction. Studies [20] have found that silicone IOLs have a significantly less effect on the refraction angle

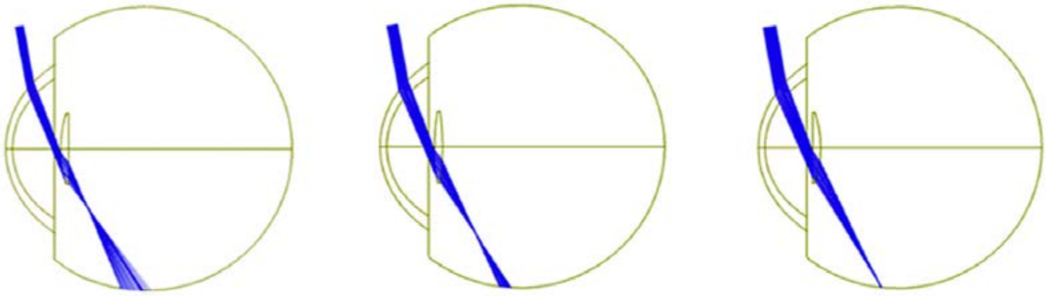

Fig. 2. Light diffusion in eyes with convex-plano IOLs (left), equi-biconvex IOLs (middle) and plano-convex IOLs (right) [21]

of light passing through the IOL and internal structures of the eye than the polymethyl methacrylate (PMMA) IOLs. In addition, patients with implanted silicone IOLs exhibit a significantly lower negative dysphotopsia incidence than patients with implanted PMMA IOLs. Moreover, acryl has a higher refractive index than silicone, and Henderson and colleagues [6] reported that acrylic IOLs seemed to lead to a higher incidence of negative dysphotopsia than silicone IOLs. It should be noted that, at present, most posterior-chamber IOLs are comprised of acryl, whereas silicone is not widely used as an IOL biomaterial.

2. An association has been established between the IOL design, diffusion of light in the eye and occurrence of negative dysphotopsia [21]. The convex-plano IOL (left) has the lowest chances for negative dysphotopsia, whereas the equi-biconvex IOL (center) with a higher dioptric power has the highest risk for negative dysphotopsia (Fig. 2).

3. The cause of the effect of the square-edge IOL optics design on the development of negative dysphotopsia has been identified. Holladay and colleagues [21] supported the opinion of Osher and Cooke that "permanent negative dysphotopsia seems related to the contour of the lens optic, primarily its truncated square edge or its edge reflectivity". Negative dysphotopsia after phacoemulsification with IOL implantation for senile cataract became more common in the 1990s primarily due to the introduction of square-edge IOL optics into cataract surgery. Square-edge IOLs (Fig. 3) became popular in the mid-90s because of their ability to reduce the incidence or retard the development of posterior capsule opacification, but they were associated with a greater effect of light diffusion. Holladay and colleagues [22] studied light diffusion in the eyes with square-edge IOL optics and those with round-edge IOL optics and concluded that the IOL edge design has an effect on the incidence of negative dysphotopsia.

4. It has also been proposed that a cataract incision located temporally in clear cornea may be associated with the incidence of negative dysphotopsia [23, 24, 25]. It is hypothesized that the corneal edema associated

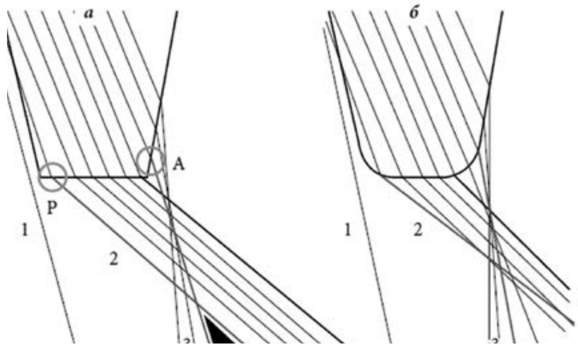

Fig. 3. Ray tracing of sharp-edged and round-edged optics [22]. Note: 1, rays passing along the IOL surface; 2, rays passing through the IOL anterior surface are retracted posteriorly; 3, rays passing through the IOL posterior surface are retracted anteriorly. The ray 2 passing through point "P" determines the posterior boundary and the ray 3 passing through point "A" determines the anterior boundary of the shadow. The partially rounded edge (b) has a radius of 0.05 mm or more and causes significant dispersion of rays 2 and 3 so that no shadow forms between rays 2 and 3.

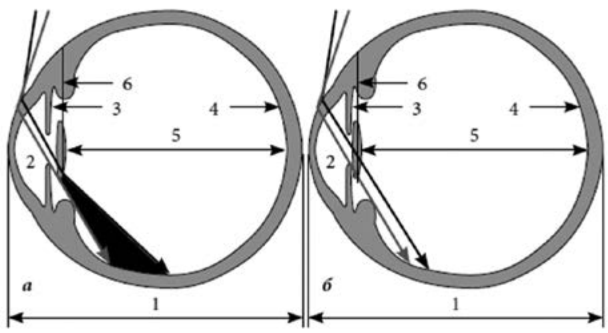

Fig. 4. Ray tracing for an IOL placed in the bag (a) and an IOL placed in the ciliary sulcus. 1, axial length of the eye; 2, anterior chamber; 3, iris; 4, retina; 5, effective focal length of the IOL; 6, primary IOL surface [21]

with a beveled temporal incision contributes to transient negative dysphotopsia. It is also believed [24] that it is reasonable to perform temporal corneal incisions during cataract extraction to reduce the incidence of postoperative negative dysphotopsia. This is believed to be associated with corneal topography and postoperative corneal edema. Local corneal edema prevents rays from passing from the temporal side of the eye to the nasal retina. Negative dysphotopsia is likely to develop if the refracted rays get to the nasal retina [25].

5. Size of capsulorhexis. Anterior capsulorhexis size has some effect on the development of negative dysphotopsia. In addition, studies have found that reflection of the anterior capsulotomy edge is projected onto the nasal peripheral retina, and if the anterior capsular opening covers the IOL optic, negative dysphotopsia incidence is significantly lower than in the presence of a large capsulorhexis due to the dispersion of rays. A capsulorhexis covering the IOL optic should be of 5 to 5.5 mm [22, 26].

6. Location of the IOL in the eye. It has been reported that the incidence of postoperative negative dysphotopsia is associated with the location of the IOL in the eye. The incidence of negative dysphotopsia was higher for in-the-bag IOL implantation with the distance between the IOL and iris ranging from 0.46 to 0.62 mm than for ciliary sulcus placement of the haptics [12, 27]. The distance between the IOL and pupil is smaller and the potential for the rays to miss the IOL optics is lower for in-the-bag IOL implantation than for ciliary sulcus placement of the haptics. In addition, no ray refraction by the IOL edge is observed, which reduces the chances for the development of negative dysphotopsia (Fig. 4) [20].

7. Position of the lens haptics with respect to the horizontal and vertical meridians of the eye. Negative dysphotopsia incidence has been found to depend also on the position of the lens haptics with respect to the horizontal and vertical meridians of the eye. Henderson and colleagues [6] observed a decrease in the incidence of negative dysphotopsia when the optic–haptic junction of the implanted IOL was placed in the inferotemporal quadrant, which blocks light entering at that angle.

8. An association has been established between the topography and anatomy of the eye and the development of negative dysphotopsia. Postoperative dysphotopsia incidence was found to be increased in eyes with an axial length of 23 to 23.75 mm. An association has been determined between the angle kappa (the angle between the visual axis and the center of the pupil) and negative dysphotopsia. Recent laboratory and clinical studies agree that a high positive angle kappa value is associated with an increased likelihood for negative dysphotopsia [21, 28]. A highly positive angle kappa value is also associated with high hyperopia. It remains possible that hyperopia and angle kappa value are potential clinical associations of negative dysphotopsia [29]. To the best of our knowledge, no association has been reported between the severity of myopia and negative dysphotopsia.

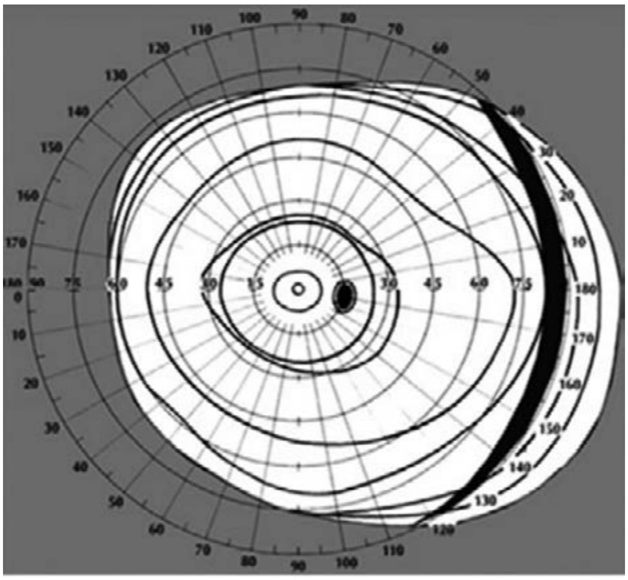

Fig. 5. A simulated retinal image of a shadow with temporal location for a 2.5 mm pupil [21].

9. An effect of the pupillary width on the incidence and severity of negative dysphotopsia has been investigated. The severity of negative dysphotopsia decreases if the pupil is dilated and increases if the pupil is constricted. Shadows on the retina can appear in the pseudophakic eyes with the 2.5 mm pupil, but not in the pseudophakic eyes with the 5.0 mm pupil [21].

10. A study with a large sample of pseudophakic patients found that complaints of negative dysphotopsia were most commonly reported by patients whose profession requires working outdoors, concentrating attention and vision (e.g., drivers) or a high intellectual ability [12]. Of note is a 20% incidence of negative dysphotopsia in patients who had uneventful phacoemulsification with transparency of the optic media, correct ratio of the sizes of the anterior capsulorhexis and IOL optics, and a well-centered IOL in the bag [10].

Diagnosis of negative dysphotopsia

In negative dysphotopsia, patients usually complain of a dark line or crescent-shaped shadow in temporal peripheral vision. Questionnaires are available to assess the presence of negative dysphotopsia. The majority of studies examining dysphotopsia use various subjective questioning in the form of verbal interviews (Jacobi et al, 2003; Marques and Ferreira, 2015), bespoke questionnaires (Kohnen et al, 2006), a validated questionnaire (Aslam et al, 2004) or through subject-initiated complaints (Shoji and Shimizu, 1996). An alternative method is to use graphics depicting visual demonstrations of different types of dysphotopsia allowing the subject to indicate which is most representative of what they perceive. Although some authors believe that it is impossible to objectively evaluate negative dysphotopsia, Makhotkina and colleagues (2016) [30] reported on the objective evaluation of negative dysphotopsia with Goldmann kinetic perimetry. In that study, the perimetric visual fields were compared with the positions of shadows reported by patients. In 3 patients with negative dysphotopsia, a shadow was drawn in the superior temporal and the inferior temporal quadrants during perimetry and the position of this shadow matched their subjective description of negative dysphotopsia. Those authors concluded that kinetic perimetry can be used for objective evaluation of patients with negative dysphotopsia because these patients had constricted peripheral visual fields or a relative temporal scotoma corresponding to the position of the shadow.

Holladay and Sympson (2017) [21] aimed to determine the cause of negative dysphotopsia using standard ray-tracing techniques. They used Zemax ray-tracing software to evaluate pseudophakic and phakic eye models to show the location of retinal field images from various visual field objects. Standard ray-tracing techniques showed that a shadow is present when there is a gap between the retinal images formed by rays missing the optic of the IOL and rays refracted by the IOL (Fig. 5).

Makhotkina et al [30] used a traditional Goldmann perimeter, and Masket et al [32, 32] used the Haag-Streit model 900 perimeter to report visual field changes in negative dysphotopsia. Masket et al reported that contralateral monocular occlusion reduces visual field defects associated with negative dysphotopsia in the fellow eye by a mean of 65% in approximately 80% of cases. Using a peripherally opaque contact lens with a 7.0 mm clear central zone for partial contralateral occlusion, they expanded their previous study to investigate the visual fields of patients with negative dysphotopsia under binocular conditions [31, 32]. This suggested the role of the central nervous system (CNS) in causing negative dysphotopsia. The pupil size was measured before and after instillation of the contact lens using the Colvard pupillometer to exclude an effect of pupillary width on visual field neasurements. It is not understood why blockage of temporal light in the fellow eye (contralateral) improves negative dysphotopsia symptoms. Masket and colleagues [32] concluded that future investigations regarding functional magnetic resonance imaging studies were planned to help explain their findings.

Methods for preventing dysphotopsia

Some researchers used reverse optic capture to reduce the distance between the IOL and the iris. With this approach, the IOL optics is moved from the capsular bag to the iris, with the haptics remaining in the confines of the capsular bag [26]. In this way, the distance between the IOL and the pupil is reduced, and the rays are prevented from missing the IOL optics and do not diffuse through the edge of IOL optics, which prevents negative dysphotopsia. Models of three-component antidysphotopic IOLs (Morcher, Germany) have been designed to ease implantation and prevent dysphotopsia. In a recent study by Rupnik and colleagues [33], none of the patients who received the 90S IOL experienced any negative dysphotopsia symptoms in the follow-up period. Those authors concluded that the 90S IOL can be used successfully to prevent negative dysphotopsia. Since it is fixated by the anterior capsulotomy, additional advantages such as prevention of anterior capsule contraction, limited tilt, stable toric axis, perfect centration on the visual axis, and a more predictable lens position, among others, may be expected, and are under investigation.

The benefit of horizontal optic-haptic junction positioning has been demonstrated [10, 22]. This approach has been reported has been reported to reduce the incidence of postoperative negative dysphotopsia to 5%. A study by Henderson and colleagues [6] comprised 305 patients (418 eyes). Those authors have concluded that positioning the optic–haptic junction of an acrylic IOL inferotemporally resulted in a 2.3-fold decrease in the incidence of negative dysphotopsia after cataract surgery. When implanted in the vertical position, Acrylic IOLs seemed to lead to a higher incidence of negative dysphotopsia than silicone IOLs.

Masket noted [19] that making the pupil smaller, which helps positive dysphotopsia, actually makes negative dysphotopsia worse. Dilating the pupil makes the symptoms better, but, unfortunately, dilation can induce glare and nighttime difficulties. Patients can be offered spectacles that block the light coming from the side that is stimulating negative dysphotopsia.

If positive dysphotopsia persists, the ophthalmologist can offer the patient a lens exchange and choose a lens [26] that has a lower index of refraction, or one that has less surface reflectivity. Utilization of a silicone IOL material may alleviate symptoms and reduce the incidences of dysphotopsia. An IOL exchange to a surgical three-piece copolymer lens or three-piece silicone IOL with reverse optic capture is recommended for symptoms of both positive and negative dysphotopsia. Some evidence has been presented supporting the hypothesis that an anti-dysphotopic IOL may prevent negative dysphotopsia while avoiding the complications typical of reverse optic capture or placing the optic in the sulcus space [34].

Conclusion

Dysphotopsias occur in 9% to more than 70% of patients after cataract surgery with the implantation of an IOL. 41% of patients with a multifocal IOL reported photic phenomena that had not been noticed before cataract surgery. The incidence of negative dysphotopsia is up to 15% in cataract surgery patients. Some patients can have symptoms of both negative and positive dysphotopsia. There is a need for novel methods of diagnosis and universal methods for complete resolution of symptoms of dysphotopsia, given the prevalence and multiple causes of, and controversial opinions on the problem, as well as the absence of clear guidelines for preventing postoperative dysphotopsia.

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Disclosures

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Abbreviations. *IOL, intraocular lens*