Straylight in anterior segment disorders of the eye

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STRAYLIGHT IN ANTERIOR SEGMENT DISORDERS OF THE EYE
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STRAYLIGHT IN ANTERIOR SEGMENT DISORDERS

FIGURE 2.1 Left: Normal ocular anterior segment, consisting of the cornea, anterior chamber, pupil and iris and lens. Right: Normal ocular anatomy. After passing through the anterior segment, the incoming light travels through the vitreous to reach the retina and form the retinal image.

The retinal image is formed in the posterior segment of the eye, but light that falls into the eye first has to pass through the anterior ocular segment (to which tear film, cornea, anterior chamber, the pupil and iris, and the lens belong) to reach the retina. (Figure 2.1) The normal ocular anterior segment contributes considerably to visual functioning: e.g. for straylight, it is known that intraocular light-scattering is for the major part influenced by the anterior segment (for 1/3 by the cornea, for 1/3 by the lens and for 1/3 by the iris, sclera and fundus). (Figure 1.2)\(^1\)\(^-\)\(^4\)

Corneal and lenticular disorders (e.g. cataract) are commonly encountered in ophthalmological practice. Due to normal aging, or when pathology is present, the influence of the anterior segment on visual quality increases even more. Considering the large influence of the ocular anterior segment on the amount of intraocular straylight and the high prevalence of anterior segment disorders in ophthalmological practice, straylight problems can also be expected to play a large role in ophthalmological practice and to be experienced by many patients. Clarification of the role of straylight measurements in clinical practice and decision making is thus of importance.

AIMS OF THIS THESIS

When the research leading to this thesis was started, the clinical use of straylight measurements was largely unknown to many ophthalmologists. Visual acuity measurement was the main and in many cases only measurement of visual functioning performed in most ophthalmological practices. However, visual acuity measurements cannot account for all visual complaints of certain patients, as is known for patients with anterior segment problems such as Fuchs’ endothelial dystrophy, cataract or opacified intraocular lenses.\(^1\)\(^,\)\(^5\)\(^-\)\(^8\) As straylight hindrance can occur while the
patient has good visual acuity, the ophthalmologist may not correctly appreciate the nature of the patients’ complaints and patients may feel misunderstood.

Furthermore, clinical ophthalmological investigation of the transparency of the ocular media is mainly based on slitlamp examination. (Figure 2.2) However, straylight complaints cannot be very well predicted or understood from slitlamp examination. The exact source and amount of straylight within the eye cannot be determined by the slitlamp. Straylight is based on forward scattered light, which is light scattered in the direction of the retina and in the direction in which it is perceived by the patient. Slitlamp examination is based on back scattered light, which is typically used only to assess the quality of the ocular tissues. Back scattered light is light scattered in the opposite direction, away from the patient and in the direction of the observer. Backward scattered light mainly reduces the amount of light reaching the retina, while forward scattered light reduces retinal image contrast by superimposing a veiling luminance upon the retinal image. Backward scattered light and forward scattered light are poorly correlated, and observations based on backward scattered light are not able to correctly assess the amount of forward scattered light or adequately locate the underlying source. A discrepancy may thus exist between the clinical observations of the ophthalmologist with the slitlamp and the complaints of the patient.

FIGURE 2.2 Slitlamp and images of the ocular anterior segment as seen with the slitlamp. Upper left: diffuse illumination. Middle left: broad beam illumination. Lower left: slit illumination. (Figure taken from: http://www.diytrade.com/china/pd/2104397/YZ5S_Digital_Slit_Lamp.html)
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This thesis aims to further clarify
1. the role of the healthy and diseased anterior ocular segment in the amount of intraocular straylight. Straylight was evaluated clinically and in-vitro for several common disorders of the anterior segment of the eye.
2. the role of straylight measurements in the clinical practice and decision making concerning corneal and lenticular disorders. The clinical usefulness and applicability of straylight measurement and the importance of straylight in comparison to the generally accepted and universally used visual acuity measurement were investigated.

INTRODUCTION TO CORNEAL LIGHT-SCATTER

The cornea

![Corneal Anatomy](image)

FIGURE 2.3 Corneal anatomy. The cornea consists of five layers (from anterior to posterior: epithelium, Bowman’s membrane, stroma, Descemet’s membrane and endothelium).

The cornea is the clear anterior part of the eye and mainly responsible for focusing light on the retina. (Figure 2.3) The cornea consists of five layers (from anterior to posterior: epithelium, Bowman’s membrane, stroma, Descemet’s membrane and endothelium). The central cornea is around 0.52 mm thick and is made for 90% of stroma. Stroma is constructed from collagen fibrils, ground substance and keratocytes, which are arranged in a very precise way to preserve corneal transparency. The function of the endothelium is to maintain adequate corneal hydration, which is necessary to preserve normal corneal thickness and clarity. A normal, healthy cornea is avascular.

Corneal light-scatter

Corneal light-scatter does not increase with age for healthy corneas, but small changes in corneal clarity at any level of the corneal anatomy can lead to an increase in intraocular straylight. The first part of this thesis will be dedicated to the influence of the healthy and diseased cornea on intraocular light-scatter. Disturbance of the highly organised ultrastructural configuration of healthy corneas, e.g. due to contact lens wear or refractive surgery, may lead to a
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decrease in corneal transparency and an increase in corneal light-scatter. Corneal disorders and dystrophies may have a large effect on intraocular light-scatter, depending on the underlying pathology.

Corneal light-scatter by healthy corneas due to contact lens wear (Figure 2.4)

Previous studies have looked at the potential influence of habitual contact lens wear on quality of vision, as disability glare is a complaint often heard among contact lens wearers. The results of these studies indicated an effect of contact lens wear on the amount of straylight, but were inconsistent to the exact outcome. Increased straylight levels compared to age-matched normal eyes or spectacle wearers were found among habitual wearers of both rigid gas permeable and hydrophilic contact lenses, although another study did not find any effect among hydrogel lens wearers. Rigid contact lens wear led to a higher amount of straylight than hydrophilic contact lens wear. However, in hydrophilic contact lens wearers the amount of straylight remained elevated after contact lens removal compared to normal levels. Among these hydrophilic contact lens wearers, slitlamp examination did not show any clinical corneal pathology, so possibly subclinical corneal changes in the epithelium might be responsible for the deterioration in visual quality. Considering the many uncertainties which still surrounded quality of vision in contact lens wearers, and the high prevalence of contact lens wear, we have attempted to clarify and quantify the effects of rigid and soft contact lens wear on straylight further. Our study of straylight in 60 habitual contact lens wearers can be found in Chapter 3. This study investigated the correlations of the straylight scores of rigid and soft contact lens wearers with contact lens characteristics, corneal changes at the slitlamp and a questionnaire evaluating subjective straylight complaints.
Corneal light-scatter by healthy corneas after laser refractive surgery (Figure 2.5)

Figure 2.5 Left: Laser in situ keratomileusis (LASIK) is performed on the corneal stroma after cutting and removing a superficial corneal lamella. Right: epithelial downgrowth is one of the complications of LASIK, in which epithelial cells grow into the interface between the anterior corneal lamella and the treated corneal stroma. (Right taken from: Krachmer JH, Mannis MJ, Holland EJ, ed. Cornea. Second edition. Philadelphia: Elsevier-Mosby, 2005.)
Patients undergoing refractive surgery usually wish to end up with perfect vision, and postoperative corneal light-scattering can be a profound source of dissatisfaction to the patient. Studies of healthy corneas undergoing laser refractive surgery (photorefractive keratectomy; PRK or laser in situ keratomileusis; LASIK) usually show good results concerning postoperative straylight, with average straylight values remaining unchanged or even improving. However, in individual patients, significant straylight increases can sometimes be found. Especially complications of the refractive procedure, such as epithelial ingrowth (Figure 2.5), haze, microstriae or interface debris, can be associated with large increases in the amount of straylight. This may lead to a visually handicapped and thoroughly unhappy patient. In Chapter 4 a study is reported of straylight values in eyes with epithelial ingrowth after LASIK. The amount of straylight slowly returns to acceptable levels after treatment of this well-known complication.


Corneal light-scatter by a diseased cornea due to Fuchs' endothelial corneal dystrophy

A diseased cornea may lead to decreased visual quality. One of the most frequently encountered corneal diseases diagnosed and treated at the corneal clinics in the Academic Medical Center in Amsterdam, the Netherlands, is Fuchs' endothelial corneal dystrophy. (Figure 2.6) It is a relatively common corneal dystrophy (prevalence around 4% of the USA population over the age of 40 years), which is slowly progressive and bilateral, though frequently asymmetric. It mostly affects females (female to male ratio of 2.5:3:1) and can be early-onset (manifesting around the 3rd decade of life) or late-onset (becoming apparent around the 5th decade of life). Fuchs'
endothelial corneal dystrophy is a disorder of the corneal endothelium, which forms a monolayer of cells on the inner portion of the cornea and preserves corneal clarity by its barrier and pump function. Fuchs’ endothelial corneal dystrophy is characterized by accelerated loss of endothelial cells, resulting in a slow increase in corneal hydration, eventually leading to corneal edema. The associated focal drop-like depositions of abnormal collagen at Descemet’s membrane lead to the formation of corneal guttæ, visible at the slitlamp as numerous small excrescences and considered essential in the diagnosing of Fuchs’ endothelial corneal dystrophy. The presence of guttæ and stromal edema will lead to deterioration of quality of vision, but visual acuity and straylight may be affected in a different way in this disease, as is discussed in chapter 5. In this study straylight measurements are shown to be a valuable tool in helping to decide when surgical treatment can be of value for these patients.


Corneal light-scatter by a diseased cornea after lamellar corneal transplantation

FIGURE 2.7 Upper: Eye after Descemet stripping endothelial keratoplasty (DSEK) with a posterior lamellar corneal transplant. Lower: slitlamp image of a cornea after DSEK with a posterior lamellar corneal transplant: the edge is visible at the inner side of the corneal contour. (Courtesy of C.P. Nieuwendaal)
The current treatment of choice for corneal endothelial dysfunction is the surgical removal of the diseased endothelium and Descemet membrane and replacing this by transplanting a thin layer of donor stroma, Descemet membrane and endothelium (Descemet stripping endothelial keratoplasty; DSEK; Figure 2.7).\textsuperscript{34-39} Compared to penetrating keratoplasty (PK), which has been the gold standard for decades, DSEK results in rapid visual rehabilitation, lower postoperative astigmatism, maintenance of better globe integrity and stability and absence of suture-related complications.\textsuperscript{34-37} DSEK leads to a significant improvement in quality of vision postoperatively.\textsuperscript{34} Although straylight improvement after DSEK and PK was found to be comparable in some studies,\textsuperscript{56,57} one study found straylight values to remain higher after DSEK than after PK.\textsuperscript{59} The graft-host interface or chronic ultrastructural changes in the anterior corneal stroma of the host could increase forward light-scatter postoperatively.\textsuperscript{54-56} Our study of patients who have undergone DSEK shows that postoperative quality of vision improves significantly up to 1 year postoperatively (chapter 5). In chapter 6, the long-term follow-up of these patients is described and quality of vision is evaluated several years postoperatively.


\textbf{INTRODUCTION TO LENTICULAR LIGHT-SCATTER}

\textit{The lens}

![Diagram of the eye showing the lens and surrounding structures.](http://www.laramyk.com)

\textit{FIGURE 2.8 The human crystalline lens is completely transparent and positioned inside a capsular bag. This bag is attached with zonules to the ciliary body and is situated behind the iris. (Figure taken from: http://www.laramyk.com)
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The human crystalline lens is a transparent structure, positioned inside a capsular bag behind the iris and in front of the vitreous body. (Figure 2.8) The lens attributes to the refractive power of the eye to focus incoming light on the retina.\textsuperscript{46} Growth of the lens continues throughout life and with age, the lens stiffens and progressively loses its transparency, resulting in presbyopia and vision loss due to cataract formation. (Figure 2.9)\textsuperscript{60-62}

![Figure 2.9 Left: slitlamp image of nuclear cataract. Right: mature cataract. (Figure taken from: http://webeye.ophth.uiowa.edu/eyeforum/atlas/pages/mature-cataract-3.html)](image)

Cataract extraction is the most commonly performed surgical procedure worldwide.\textsuperscript{15,63} The cataractous crystalline lens is removed by phacoemulsification. After removal of the crystalline lens, the capsular bag is cleaned to remove as much lens epithelial cells as possible and an intraocular lens implant (IOL) is placed inside the bag (Figure 2.10), in these ways reducing the chance of postoperative capsule opacification.\textsuperscript{43}

**Lenticular light-scatter**

The young human lens is clear and transmits nearly 100% of incident light.\textsuperscript{62} Disturbance of the high spatial order of the lens fibres and aggregation of proteins within the lens with increasing age result in cataract formation and increased forward light-scattering (Figure 2.11).\textsuperscript{2,7,8,64,62} Separate parts of the lens contribute in a different manner to intraocular forward scatter, which is a predominant cause of visual loss in early cataract.\textsuperscript{64,65} Straylight is better correlated to cataract severity than both visual acuity and contrast sensitivity,\textsuperscript{2,64,66} and a better predictor of functional visual loss than visual acuity measurement.\textsuperscript{9,11} All forms of cataract give rise to increased straylight, although cataracts with components of posterior subcapsular cataract usually elevate straylight.
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**Figure 2.10** Intraocular lens implant (IOL) inside the capsular bag after cataract extraction.

**Figure 2.11** Left: when the crystalline lens is clear, the incoming light is focused on the retina and a clear and distinct image is formed. Right: Cataract formation disturbs the high spatial order of the lens fibres and increases the amount of intraocular forward scattered light. The retinal image becomes hazy and blurred.
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levels most.\textsuperscript{10,18,24,26,60,67} The effect of cataract on straylight values is comparable to that of extreme aging of the lens\textsuperscript{2,18,39} and increasing cataract severity elevates levels of intraocular straylight proportionately.\textsuperscript{10,18,54} Mean intraocular straylight for a mild cataract is around 1.4log(\textit{s}), which is approximately a threefold increase compared to young, healthy eyes, but in advanced cataract straylight levels can be much higher.\textsuperscript{60,66}

As cataract and subsequently cataract surgery are highly prevalent among the population,\textsuperscript{10,14,63} it is necessary to obtain a precise understanding of the functional vision losses and accompanying complaints due to lens opacities, and the visual improvement which can be expected from cataract surgery. The second part of this thesis will be dedicated to further elucidating the influence of the cataractous lens, the lens capsule and IOLs on quality of vision and intraocular straylight.

Lenticular light-scatter and cataract surgery
As cataract is such a prevalent disorder and so many resources are spent on cataract surgery, it is adamant to be able to predict postoperative outcome as good as possible. Although postoperative results of cataract surgery are generally good, outcome occasionally surprises and gives an unhappy patient and consequently doctor. Indications for cataract surgery are usually based on slitlamp examination and visual acuity measurement.\textsuperscript{2,18} As the slitlamp image consists of backscattered light and visual acuity testing may underestimate functional impairment,\textsuperscript{2,10,13,16,65} these preoperative examinations may be insufficient for effective preoperative surgical counseling.\textsuperscript{5-7,9,12,17,18,26,66-68} Other tests which more faithfully reflect functional vision loss may be needed to improve the preoperative decision process.\textsuperscript{5,7,9,12,18,25,66-68} Because forward scatter is known to have functional importance\textsuperscript{9,26,66} and is not correlated with visual acuity,\textsuperscript{7,8,14,16,63,66,67} additional preoperative straylight measurement could be a useful addition to the surgical decision making.\textsuperscript{2,18,67}

In chapter 7, the value of straylight measurements in patients with cataracts is evaluated. It is shown that straylight is almost equally important as visual acuity for subjective quality of vision and that straylight measurements are very helpful in determining the right moment for cataract surgery.


Lenticular light-scatter in pseudophakic eyes
After cataract extraction, restoration of straylight levels to those of normal, healthy, young eyes is expected.\textsuperscript{16,13,68} The old and opacified crystalline lens is replaced by a clear, thin IOL, which scatters
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even less light than a young, transparent crystalline lens, one might assume. This makes the situation after cataract extraction comparable to or better than that of a young, healthy eye as far as intraocular lenticular forward light-scatter is concerned. Several studies have shown that straylight improves after cataract extraction in pseudophakic eyes, but that this is certainly not true for all pseudophakic eyes. Surgery or other unknown factors might play a role postoperatively in keeping straylight levels elevated, as well as opacification of the capsular bag or the IOL. Age-related changes to the eye, such as age-related pigmentation changes or vitreous turbidity, may play a role as well.

The capsular bag helps in adequately centering the IOL in pseudophakic eyes. It envelops the posterior part of the IOL and a ring of anterior capsule usually partly covers the front part of the IOL, depending on the size of the capsulorhexis (the opening in the anterior lens capsule through which the cataract is extracted during the operation). After cataract extraction, both the posterior part (posterior capsule opacification; PCO, Figure 2.12) as the anterior part of the remaining capsular bag may opacify or contract with migration and proliferation of residual lens epithelial cells. Capsule opacification is common after cataract surgery and will decrease visual quality after cataract extraction. Although standard visual acuity measurement is of limited value in predicting loss of visual performance in patients with capsule opacification, straylight measurement is very sensitive to the presence of central PCO. Increased light-scatter values were found in eyes with PCO, despite relatively good visual acuity, and the straylight value was shown to be proportionate to the percentage of pupil area which is occupied by opacified lens capsule.

Chapters 8, 9, 10 and 11 focus on the effect of opacification of the capsular bag on quality of vision after cataract extraction. Chapter 8 describes a clinical study in which it is shown that an opacified anterior lens capsule contributes to elevated straylight levels after cataract extraction. The effect of capsulorhexis size and opacity on the amount of straylight is quantified, and an advice is given concerning minimum dimensions of the capsulorhexis which are needed to prevent straylight problems in twilight.


![YAG Laser Capsulotomy](http://www.avclinic.com/yag_capsulotomy.htm)

FIGURE 2.13 An Nd:YAG capsulotomy is the treatment of choice for posterior capsule opacification. With a laser a central opening is made in the opacified posterior capsule, clearing the visual axis. In the left lower image the slitlamp image is shown of PCO with retrograde illumination. In the right lower image the same eye is shown after Nd:YAG capsulotomy, with a central hole in the posterior capsule and a clear visual axis. (Upper image: http://www.avclinic.com/yag_capsulotomy.htm. Lower image: http://www.avclinic.com/yag_capsulotomy.htm)
Nd:YAG capsulotomy is the treatment of choice for posterior capsule opacification (Figure 2.13). With a laser a central opening is made in the opacified posterior capsule, clearing the visual axis. The size of the posterior capsulotomy is important for the resulting visual performance after laser treatment. Previous studies have shown that after laser capsulotomy in most cases visual quality improves and the amount of forward light-scatter diminishes. In some cases no improvement or even deterioration in straylight is documented after Nd:YAG capsulotomy, but this could be caused by an insufficiently sized capsulotomy. Small capsulotomies were shown previously to have unsatisfactory effect on quality of vision. Although visual acuity may improve adequately with a small capsulotomy, straylight was shown not to improve as much or even to deteriorate and to remain significantly higher than in eyes with wide capsulotomies. Capsule remnants or the capsulotomy border which remain visible in the pupil area could increase straylight after laser treatment, so it is advised to create a capsulotomy larger than the pupil diameter.

Chapter 9 illustrates the functional problems which may arise from a small capsulotomy by describing a patient with glare complaints and increased straylight due to the capsulotomy edges, which were visible in the pupil area. Straylight levels returned to normal and the complaints disappeared after widening the capsulotomy.


Lenticular light-scatter in-vitro

Previous studies have attempted to relate patients' visual disability to the severity and extent of PCO or the morphological classification of capsule opacities. Clinically, 2 morphological types of PCO are recognized, the fibrosis type (which produces folds and wrinkles in the posterior capsule) and the pearl type. Variable PCO morphology may explain diverse effects on visual acuity and straylight, as fibrous plaques, Elschnig's pearls and non-uniform clouding are supposed to cause different visual symptoms. Compact fibrosis which may appear to be clinically severely disturbing may be less harmful to visual functioning than more transparent areas with pearl formation, as these last areas will cause more intraocular forward light-scatter. PCO is typically very heterogeneously distributed and its visual effect varies depending on the relation with the visual axis and pupil dilation.

In-vivo, retro-illumination cameras in combination with computer systems have been used to measure the percentage of PCO and analyze the texture. These images are compared to visual function tests, such as low contrast visual acuity or straylight measurements. However,
data on the effect of PCO morphology on straylight are limited. Clinical assessment remains problematic as PCO is evaluated with backscattered light, while the patient’s vision is degraded by forward scattered light, which leads to a poor correlation between the clinical appearance at the slitlamp and the patient’s visual symptoms. Images acquired by retro-illumination and backscattered-light may overrate the visual impact of PCO.

As in-vivo light-scattering by the crystalline lens or IOL is difficult to separate from the visual influence of other ocular media, in-vitro studies are required to obtain a better understanding of the isolated light-scattering characteristics of the lens, the lens capsule or the IOL. An optical set-up was designed and validated to measure light-scatter of crystalline lenses, potential cataract-stimulating filters and spectacle lenses (Figure 2.14). With this set-up, a clear, monofocal IOL was shown to have a lower straylight value than a normal, transparent, healthy human crystalline lens, irrespective of its age. Clean spectacle lenses were shown to generate a clinically insignificant amount of straylight compared to the normal level of intraocular straylight.

![Simplified drawing of validated in-vitro set-up for optical measurements of forward light-scatter from intraocular lenses (IOL).](image)

This set-up was used to study and quantify the effect of lens capsules and opacified IOLs in-vitro. In chapters 10 and 11, the isolated light-scattering characteristics by opacified capsular bags were measured in-vitro and were compared to the specific morphology and severity of capsule opacification. Small-particle light-scattering was shown to be important in PCO, while PCO may also have a refractile component.


Lenticular light-scatter of opacified IOLs

FIGURE 2.15 Explanted opacified intraocular lens with a fine, pigmented deposit covering the central anterior part of the optic.

In pseudophakic eyes, the transparency of the implanted IOL has an important influence on postoperative quality of vision. IOL opacification may lead to severe visual impairment, such that it even justifies IOL explantation (Figure 2.15). However, it may be difficult to evaluate clinically the visual disturbance of an opacified IOL, as visual acuity may remain at a reasonable level despite severe subjective complaints of reduced visual quality, which may lead to under-detection and underestimation of the problem. In some patients visual acuity even diminished after explantation of the opacified IOL, while these patients rated postoperative
quality of vision better than before IOL explantation. Visual acuity measurement alone turns out to be an insufficient criterion to rely upon during preoperative decision making, and additional tests which measure other aspects of visual performance are necessary. Straylight measurements are particularly sensitive in documenting the visual effects of opacified IOLs. This can be explained by our findings in chapters 12 and 13. The optical set-up (Figure 2.14) offers an excellent opportunity to evaluate and isolate the visual effects of an opacified IOL in-vitro. In chapter 12 is shown that opacified IOLs lead to a severe increase in the amount of forward light-scatter, while having little effect on visual acuity. Chapter 13 describes the unique chance to link in-vitro optical measurements of light-scatter of an explanted IOL with in-vivo functional measurements of straylight. These measurements correlate exceedingly well. Chapters 12 and 13 support the conclusion that straylight measurements are a useful addition to the surgical decision making process in case of a patient with subjective complaints and an opacified IOL.


REFERENCES

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