Chapter 1

General introduction
Many of you will recognize the experience of having vision difficulties in the presence of a bright light source in your field of view, for example in a room where you have difficulty recognizing a person in front of a bright window. The bright window causes a veil of light, which deteriorates the contrast of the person you would like to see clearly. Such conditions are not represented when a well-illuminated letter chart test is used in a dimly lit room when your ability to distinguish small details is measured in the office of a clinician. This thesis contains studies that reveal methods and results that help to understand the effects of such veils of light on quality of vision, specifically in relation to cataract surgery. This introduction section starts with a basic description of the eye’s anatomy and cataract surgery and leads to the objectives and outline of this thesis.

The human eye is a light sensory organ that captures visual information, crucial for many of the tasks a human performs. Figure 1 shows the basic anatomy of the eye.

![Anatomy of the eye](https://nei.nih.gov/photo/anatomy-of-eye including sclera and ciliary muscle)

*Figure 1 Anatomy of the eye.*

The sclera is the rigid white outer layer covering the eyeball with at front of eye the transparent cornea acting as an optical element. Behind the cornea, the colored iris divides the eye chamber filled with aqueous humor into an anterior and a posterior part. The crystalline lens is the second optical element located just behind the iris. The vitreous body is a transparent jellylike tissue between the crystalline lens and the retina. The photoreceptors, cones and rods, are located as a layer in the retina. There are red, green, and blue light-sensitive cones; the rods are not color sensitive but are responsible for
vision at low light levels. The highest density of cones is in the fovea, the most central part of the macula, also called the yellow spot. In the surrounding retinal periphery, there is a high density of rods and a lower density of cones. There are no photoreceptors present in the blind spot because this is where the optic nerve leaves the eye to connect with the brain. Objects are imaged on the retina, detected and processed by the rods and cones, and signals are then transferred through the optic nerve to the brain for interpretation.

The eye enables humans to navigate under very different light conditions. The retinal illuminance is controlled by the iris acting similarly to a diaphragm in a camera. If the luminance of the scenery is low, like for example in an overcast night, the rods take over from the cones to provide visual information. A dim star made visible by peripheral located rods may disappear when the image of the star moves to the rod-free fovea. Motion is best detected by the peripheral retina, while visual acuity is higher in the central retina, i.e., the fovea.

In a well-focused eye, the cornea and the adjustable crystalline lens image an object onto the retina. Glasses, contact lenses or refractive surgery may be applied to correct for refractive errors. Accommodation is the ability to maintain a sharp image on the retina by changing the crystalline lens power. Lens power changes are the result of contraction of the ciliary muscle changing the crystalline lens curvatures. Reading is easy at a young age when the accommodative amplitude is large. With aging, the crystalline lens becomes stiff and is not able to accommodate anymore. As a consequence, nearby objects are not sharply imaged onto the retina anymore and people will need reading glasses.

Ageing may also result in a cloudy crystalline lens causing scattering of light over the retina: stray light. An increase in stray light deteriorates the contrast of images at the retina and thus contrast sensitivity is reduced. When the cloudiness of the lens becomes noticeable to the person involved, the cloudy lens is called cataractous. Figure 2 illustrates the effect of a reduction in contrast caused by increased stray light caused in a mild cataract case. The pedestrian in front of an oncoming car is less visible for a person with mild cataract compared to a person with healthy eyes.

Figure 2 Night driving scene for person with healthy eyes (left) and for person with a mild cataract (right)
When retinal stray light becomes too large and/or visual acuity becomes too low, resulting in patient complaints, a cataract extraction procedure may be performed. This is a surgical intervention where the crystalline lens is removed, leaving the lens capsule in place. An intraocular lens is then implanted in the empty lens capsular bag to restore vision. Figure 3 shows a typical intraocular lens consisting of an optic body and two haptics to fixate the lens in the remaining lens capsular bag.

Figure 3 Intraocular lens

Cataract surgery is the most successful and most often performed surgery to date; it is executed more than 20 million times a year worldwide. During the last two decades, cataract surgery technology has evolved enormously. Improvements include advancements in surgical techniques, intraocular lens design and intraocular lens power calculation. Lens power calculation is important to minimize the refractive error after surgery. Today, the majority of the intraocular lenses are monofocal. This means that patients need reading glasses for seeing near objects because the lenses do not accommodate. New developments in intraocular lens design aim to reduce spectacle dependency for intermediate and near vision while maintaining good uncorrected distance vision without any visual side effects. Recently introduced multifocal, trifocal and ‘extended range of vision’ intraocular lenses perform better than their predecessors, but improvements are still needed.

It remains a challenge in cataract diagnosis to determine if surgery needs to be performed on patients who have visual acuity which is considered to be adequate but who have significant visual complaints. Most commonly, such complaints are presumed to be caused by increased retinal stray light. While visual acuity is determined easily with the well-known letter chart, the amount and the effect of stray light is not so easily determined. In a slit lamp exam, a clinician assesses the condition of the crystalline lens and this is, depending on the type of cataract, not a trivial task. Light from the slit lamp incident on the crystalline lens is scattered backward into the clinician’s eye, and is scattered forward
onto patient’s retina. An increased retinal stray light level and a reduced visual acuity are both manifestations of cataract but they are to a certain extent independent of each other: cataract patients may have a normal visual acuity and clearly abnormal stray light levels, and vice versa. To date, there is no established, widely used method to measure the amount of retinal stray light.

A remaining challenge after cataract surgery is the formation of after-cataract, i.e., cloudiness across the intraocular lens optic, again causing an increased retinal stray light level several years after the initial surgery. This cloudiness is caused by proliferation of remaining lens cells which grow on the lens capsule, thereby causing capsular opacification. Although after-cataract can easily be removed by laser treatment, there is a significant incidence causing a large economic burden on the health care system.

In intraocular lenses, inhomogeneities in the optic body and lens surface irregularities may occur which are sources of retinal stray light. These may result in complaints such as blurry and hazy vision and potentially affect the safety and quality of life of the person involved.

To conclude, there are challenges remaining in many parts of the total cataract surgical-procedure. Investigations that aim to understand the sources of retinal stray light and its effects on visual performance may contribute to better vision in elderly patients and thus to healthy aging.
Outline of this thesis

The objectives of this study were (1) to determine the impact of stray light on visual performance, (2) to evaluate a new technique that aims to quantify stray light, and (3) to determine the contribution of intraocular lenses to retinal stray light.

In Chapter 2, two case studies are presented, discussing the blurry and hazy vision of two pseudo-phakic patients due to stray light originating from their intraocular lenses. Their visual complaints led to intraocular lens exchange; the stray light was caused by the presence of micro-vacuoles in the optic body of these intraocular lenses. Micro-vacuoles are often referred to as glistenings due to their appearance when visualized, e.g., in a slit lamp exam. The glistenings induce retinal stray light which results in the visibility of a halo around light sources. Such halos are clearly visible at night and can be annoying when driving a car, illustrating the clinical relevance.

In Chapter 3, the development of the Rostock Glare Perimeter is described. This device was developed in order to measure the size of the halo in the presence of a glare source.

Chapter 4 presents a study conducted with the Rostock Glare Perimeter in phakic and pseudophakic patients.

In Chapter 5, the effect of retinal stray light on the visual performance of healthy, phakic subjects was studied. Different levels of retinal stray light were induced by using photographic filters. Halo size, luminance threshold detection, and contrast sensitivity with and without the presence of a glare source were measured as function of stray light level.

Chapter 6 describes two methods for in-vitro assessment of stray light of intraocular lenses. The two combined methods have the capability to record both forward and backward light scatter and to separate the stray light contribution of the intraocular lens from contributions originating from the cornea, the vitreous body, and/or the retina.

Chapter 7 presents the stray light characteristics of the most commonly used intraocular lenses, stratified according to material and lens design, using the measurement methods described in Chapter 6. Hydrophobic and hydrophilic acrylic lens materials were tested together with refractive spherical, aspheric, and diffractive multifocal intraocular lens designs.

Stray light induced by micro-vacuoles in four different acrylic intraocular lens types is addressed in Chapter 8. The stray light measurements were verified using optical theory.

Chapter 9 contains a general discussion and concludes with an outlook on the future.