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REFRACTIVE SURGERY

Retinal straylight and light distortion phenomena in normal and post-LASIK eyes

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Abstract
Purpose To assess the relationship between measures of light distortion and retinal straylight in normal and post-LASIK subjects.
Design Cross-sectional, non-randomized, masked observational case series
Setting Clinica Oftalmologica Novovision, Madrid, Spain.
Methods Thirty eyes from 30 healthy subjects (mean age 33.9±8.3 years old; mean spherical equivalent (MSE) −2.06±1.40 D) and thirty six eyes from thirty six refractive surgery patients (mean age 36.1±7.7 years old; mean preop MSE −3.43±2.23 D) were examined with the Starlights and the C-Quant straylightmeter in a case-control study.
Results The age of both treated and control groups was not statistically different ($p>0.05$). Statistically significant differences between controls and post-LASIK eyes were found for luminous distortion index (LDI), but not for retinal straylight. Correlation analysis yielded significant correlation between retinal straylight Log(s) values and BCVA measures ($r=0.379$, $p=0.002$). Control subjects showed significant correlation between MSE and retinal straylight Log(s) values ($r=-0.650$, $p<0.001$), while post-LASIK eyes showed a significant correlation between LDI and Log(s) values ($r=0.338$, $p=0.044$) and between Log(s) values and BCVA ($r=0.460$, $p=0.005$). Correlation between measures obtained by both methods was higher after LASIK than in control eyes, although values were quite scattered in any case.
Conclusion Light distortion phenomena and retinal straylight measures are correlated in both normal and postsurgical eyes. Both parameters are increased in LASIK subjects compared to control non-operated subjects.

Keywords Halo phenomena · Retinal straylight · Refractive surgery · Disability glare

Introduction

Among the factors limiting visual performance of the human eye, intraocular light scatter, wavefront aberrations, and diffraction may be found. Luminous distortions under dim light conditions are some of their manifestations, several types of which may be identified, such as halos, starburst, or glare.

None of the authors has a commercial interest in any of the instruments used in the present study.

The authors indicate no financial support or financial conflict of interest involved in the design and conduct of the study (A.C., J.M.G-M, C.V., T.F-B, S.G-L..); collection, management, analysis, and interpretation of the data (A.C., J.M.G-M, C.V., T.F-B, S.G-L..); and preparation, review, or approval of the manuscript (A.C., J.M.G-M, C.V., T.F-B, S.G-L.). The study was approved by the Clinica Oftalmologica Novovision review board. The study protocol was approved by and all study procedures adhered to the recommendations of the declaration of Helsinki. Written consent was obtained from all participants.

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Night vision disturbance (NVD) has been described among patients who had undergone corneal laser refractive surgery procedures, but may have different origins [1]. Retinal straylight (disability glare), contrast sensitivity, and image degradation are included among NVDs according to the description by Fan-Paul et al. [2]. Within the surgical context, starburst is attributed to corneal haze in the postoperative period, while halo phenomena would occur due to the transition zone between ablated and non-ablated cornea within the pupillary area [3, 4]. These halo phenomena have more to do with a refractive effect being different from the halo generated by dispersion of light through edematous cornea. However, is not clear whether these phenomena can be classified separately, as it is known that several forms of visual distortion coexist [5]. Thus, it is interesting to isolate different measurements that correlate with halo and other forms of visual distortion, in order to better characterize their aetiology and variability factors.

Visual distortion causes contrast loss in the retinal image, and that can reflect subtle changes in the transparency/transmittance of the optical ocular media; hence, the estimation of this parameter has undergone an increasing interest in cataract and refractive surgery procedures. It would therefore be of great interest to know if visual distortion measures correlate with other optical quality measures usually obtained with different tools within the clinical and research environment. It has been stated that refractive irregularities and wavefront aberrations are not enough for explaining the spread of the point spread function (PSF), suggesting the existence of a yet not well-understood link between this parameter and the scattering of light on the small particles of the internal ocular media. This scatter would be responsible for the luminous distortions that mainly produce a decrease in contrast sensitivity (PSF with angular radius <0.1º). Aberrations and refractive error decrease visual acuity and also produce partial loss of contrast sensitivity (PSF with angular radius < 0.1º). (Van den Berg, personal communication 2009).

Villa et al. [6] have shown correlations between halo phenomena (probably better referred to as light distortion [5]) and secondary astigmatism, coma and spherical aberration. However, there are more sources that contribute to light distortion [5], and retinal straylight could be one of those.

The aim of this study is to determine the relationships existing between the psychometrical measures of light distortion and psychometrical determination of retinal straylight in normal and post-refractive surgery human eyes.

Methods

Thirty eyes from 30 healthy subjects and 36 eyes from 36 corneal laser refractive surgery patients were examined. The study followed the tenets of the Declaration of Helsinki, and informed consent was obtained from all patients after the nature of the study had been explained to them.

Non-surgical eyes

The non-surgical sample (control arm) comprised subjects aged between 20 and 44 years of age(33.9±8.3 years) with refractive errors ranging from 0 to −4.00 D (mean spherical equivalent [MSE] −2.06±1.40 D). None of the eyes examined had a history of previous surgery, ocular infection, or media opacities. Monocular best-corrected visual acuity (BCVA) was measured using a high contrast Bailey–Lovie LogMAR chart.

Surgical eyes

The surgical eye sample comprised subjects aged between 23 and 51 years of age (36.1±7.7 years). Refractive errors prior to surgery ranged from +2.00 to −6.50 D of sphere and up to 3.00 D of cylinder (MSE was −3.43±2.23 D). Surgical routine for laser in situ keratomileusis (LASIK) surgery was according to international standards, and the commonly accepted criteria for refractive surgery procedures were followed. After a 160-μm, 9.0-mm diameter flap creation with a Hansatome microkeratome (Chiron Vision, model 2765; Bausch & Lomb, Claremont, CA, USA), wavefront optimized ablation profile ablations were produced according to Munnerlyn's algorithm, using the Allegretto Wave Eye-Q 400 Hz (Wavelight, Erlangen, Germany). All surgical procedures were uneventful and considered successful. For this study, all subjects were prospectively examined 9 months post-surgery. Exclusion criteria included a significant degree of variability on the light distortion index (LDI), which is described below, significant surface irregularity (SRI>1), or decentred ablation by 0.5 mm or more from pupil centre to ablation geometric center. Biomicroscopic findings were also investigated in order to exclude cases of significant haze, striae, flap wrinkling, or epithelial defects. Visual acuity was measured best-corrected (BCVA) using a high-contrast Bailey–Lovie LogMAR chart.

Retinal straylight seasurement

Psychometrical determination of retinal straylight was performed using the "compensation comparison" method through its commercial version, the C-Quant straylight-meter (Oculus DG, Germany). Essentially, this method presents exactly the same stimuli to the subject as the direct compensation method described in previous reports [7], and implemented in previous versions of the instrument [8]. In contrast, in the compensation comparison method, two stimuli of the direct compensation method are presented to and compared by the subject simultaneously [9]. The method consists of a series of concentric rings. The smallest ring — the test field — is divided into two halves , which the patient is asked to look at while a concentric ring flickers with varying intensity and frequency, making it essentially a photopic test; this concentric ring would be the straylight source. The flickering in the straylight source induces a certain amount of perceived flickering in the test field. The patient is asked to compare both halves of the test field, one of which has some counterphase flickering added, and indicate which side flickers stronger by pressing a button. The answers will define a psychometric function from which the straylight value is obtained.

The method has been extensively studied [10–12], providing repeatable and reliable measures of retinal straylight [10, 13], and applied to a variety of surgical [7–9, 14] and clinical conditions [15]. Three consecutive measurements were taken on each subject. All measurements used for analysis were considered reliable by the system, that is, the estimated standard deviation (ESD) and shape factor (Q) values were lower than 0.08 and higher than 1.00 respectively. A time interval between 30 seconds and 1 minute was allowed between measurements for the patient to rest from the task. Each single measurement lasted about 1.5 to 2 minutes.

Measures of light distortion

Light distortion, formerly referred to as halo phenomena [5], was assessed by measuring the distortion in shape and size of a light source using the Starlights System® (v.1.0, Novosalud, Valencia, Spain). After dark adaptation, each subject was asked to discriminate a small luminous source around a central high-luminance stimulus, following the methodology described in previous reports [6, 16]. A distortion index, so-called LDI or luminous distortion, is obtained for assessing the effect of halos on night vision. This index represents the percentage of the total area explored where the peripheral stimuli presented are not seen due to the light distortion induced by the central source on the patient's retina under mesopic conditions. The system has been described previously, and consists of a black screen with a central light which acts as a fixation stimulus and source of light, subtending an angle of 0.34° (1.2 cm) and surrounded by white light-emitting diodes (LEDs) radially along 12 semimeridians up to 30º . A total of 120 stimuli are tested (ten stimuli in each of the 12 semimeridians 30º apart from each other). However, the percentage value obtained does not represent the percentage of stimuli seen but the area seen. Luminance is about 0.17 lux or 0.054 cd/m [2], in the range of night vision.

To measure the LDI, the patient is seated at 2 meters from a projection screen where peripheral stimuli are presented around a central source of light. Peripheral stimuli (0.2 mm in diameter or 0.06º) are presented at random intervals between 0.25 and 0.75 s up to an angle of 2.3º (4.6º central area) while the patient looks at the central spot, which subtends an angle of 0.34º). Although the room was in total darkness, the iluminance on the eye at the test distance due to the central source of light was 0.27 lux. LDI represents the area where stimuli are not seen due to light distortion caused by central source of light over the total area under evaluation, and is expressed as a percentage [6].

While the room is in total darkness, the source of light acting as distortion stimulus places the patient under mesopic conditions at the eye's plane, thus inducing some pupil miosis. Although at the time of surgery only Colvard pupilometry under scotopic conditions was recorded, pupil size has recently been measured in a similar cohort of patients with regard to ametropia and age. These measures were conducted with an open-field infrared autorefractometer (Grand Seiko, WAM5500, Hiroshima, Japan) under the same conditions (same LED at same intensity and distance placed at 2 meters). The average pupil size was 5.26± 0.84 mm, which may be assumed for the patients being reported here.

This instrument has been recently proven to be sensitive enough to quantify halo phenomena in post-LASIK patients [6, 16], being also useful to judge the improvement in visual performance after visual rehabilitation in complicated LASIK surgery [17]. As in previous reports, three consecutive measures were obtained from each subject, and then averaged prior to analysis. Subjects were excluded when the standard deviation of three repeated measures exceeded 10% the average value. In the rare cases where this happens, it is usually due to poor tear stability or patients with lack of attention during the test. In the current study, two patients were not included due to this criterion.

Statistical analysis

Data were analyzed using the statistical package SPSS version 15.0 (SPSS Inc, Chicago, IL). Normal distribution of variables was assessed by the Kolmogorov–Smirnov normality test, and homogeneity of variances was assessed through Levene's test. Independent samples *t*-test was applied to compare data from clinical and control population after normality of variance was assessed by Levene's test. Bi-variate correlation analysis was used to evaluate correlations of LDI with retinal straylight values. The level of significance was established at $\alpha = 0.05$.

Results

Descriptive statistics and statistical comparisons of the results of halo disturbance and retinal straylight obtained for both groups are displayed in Table 1. Standard deviation of repeated measures of LDI were lower than 10% of the average value in all cases studied, and around 0.07 log(s) units on average for the retinal straylight measures, agreeing with previous reports [10, 13]. The age of both treated and control groups was non-statistically different ($p>0.05$), thus reducing the chance of detecting differences not due to the treatment but to physiological variations in ocular media, such as those associated with age. Significant differences between controls and post-LASIK eyes were found for LDI, but not for retinal straylight, possibly due to the photopic character of retinal straylight measurement with the compensation comparison method (Fig. 1). Average LDI was 0.89 and 1.72 before and after surgery, corresponding to an increase of 79% or a factor of 1.93 (average value after/average value before).

Correlation analysis between the different parameters yielded significant correlation between retinal straylight Log(s) values with BCVA measures ($r=0.379$, $p=0.002$) (Fig. 2). Done by group, non-surgical subjects showed significant correlation between MSE and retinal straylight Log(s) values ($r= 0.650$, $p<0.001$), while post-LASIK eyes showed a significant correlation between LDI and Log(s) values ($r=0.338$, $p=0.044$) and between Log(s) values and BCVA ($r=0.460$, $p=0.005$).

Regression plots of halo disturbance measures against retinal straylight by group are displayed in Fig. 3. Correlation between measures obtained by both methods was higher for the post-LASIK eyes, although values were quite scattered.

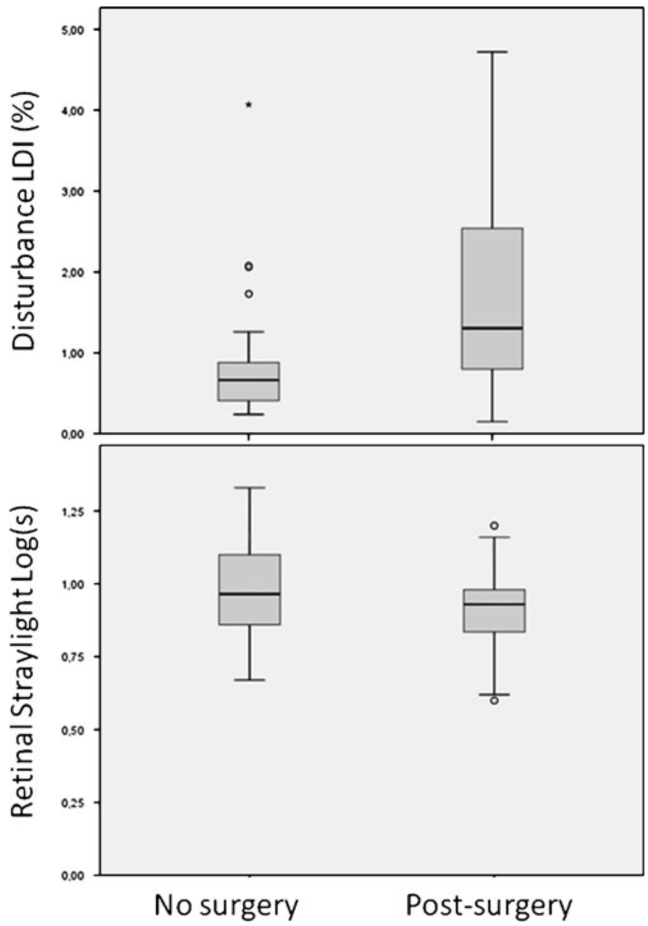

Fig. 1 Boxplots representing the mean and variability of disturbance index LDI (*upper*) and retinal straylight (*lower*) in non-surgical and surgical eyes measured. *Stars* and *circles* represent outliers

Table 1 Descriptive statistics (mean±SD) and statistical comparison of the results obtained for light distortion (% LDI) and retinal straylight [Log (s)] for both groups examined. Note that values for the non-surgical eyes correspond to refractive correction and best-corrected visual acuity, whereas for the post-LASIK eyes correspond to attempted refractive correction and uncorrected visual acuity post-op

	Non-surgical	Post-LASIK	*P*
Age (years)	33.9±8.3	36.1±7.7	0.285
Sphere (D)	−1.63±1.30	−2.89±2.18	0.007
Cylinder (D)	−0.86±1.02	−1.08±0.78	0.316
MSE (D)	−2.06±1.40	−3.43±2.23	0.005
BCVA LogMAR	−0.05±0.05	−0.06±0.06	0.403
Light distortion index (%HDI)	0.89±0.81	1.72±1.22	0.002
Retinal straylight Log(s)	0.98±0.16	0.91±0.14	0.091

MSE =mean spherical equivalent; BCVA = best-corrected visual acuity

Discussion

This study shows that, although weak, some correlation exists between retinal straylight measured with the C-Quant compensation comparison method and LDI measured with the Starlights system, and that both measures increased after LASIK. Both systems assessed the visual response of the patient to the effects of light disturbance.

Within the eye there are two main sources of halo phenomena, coming from diffractive origin (such as Sattler's veil in situations of corneal edema [18]) and refractive origin, mainly due to spherical aberration. In a recent editorial, Klyce pointed out that the HDI given by the Starlights system, as used in previous reports on this methodology, would more appropriately be defined as "light distortion index", since other optical effects may have similar consequences in the distortion of incident light

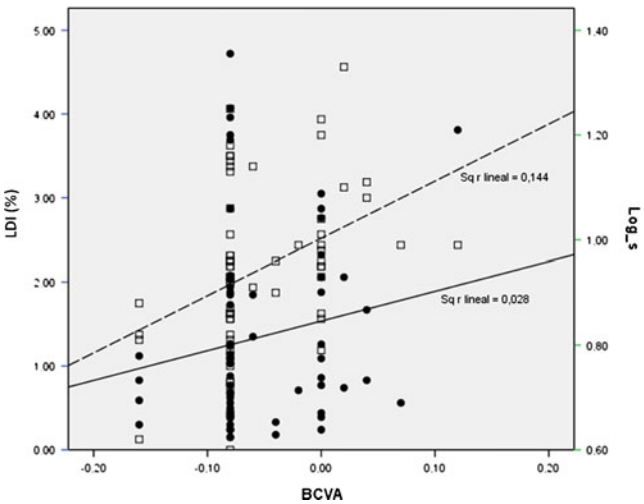

Fig. 2 Regression line between halo distortion index (% LDI) (*full circles* and *solid line*) and retinal straylight Log(s) (*empty squares* and *dashed line*), against best-corrected visual acuity (LogMAR units) for the whole sample

[5], and that is the reason why the authors changed the definition of the parameter measured to LDI for the purposes of the current study. Despite this, the information provided by the instrument is of great clinical value in trying to explain the visual complaints following corneal surgery.

Increase in outcome values after surgery was statistically significant for light distortion, agreeing with previous results [6, 19], but not for retinal straylight measurement. At first glance, it could be thought that any reason beyond the occurrence of “haze” could justify an increase in this parameter, but this has been outlined as exclusion criteria. The significant correlation between halo disturbance index and retinal straylight for the post-LASIK eyes only, and not for non-surgical eyes, is a remarkable finding. Also, it would be expected that, if correlations exist, it would be significant for the non-surgical sample and not after surgery, due to the photopic character of the retinal straylight measurement and mesopic for the Starlights system. Pupil size when considered alone has not in fact been foundto be a significant contributor to either LDI [6] or Log(s) [12] values in normal healthy subjects. A recent report found no significant increase of retinal straylight values 1 month following refractive surgery procedures [7], which agrees with the lack of significant differences between non-surgical and post-surgery eyes in the sample analyzed in the present study. LDI values have been reported to increase after successful refractive surgery procedures by a factor of 2.15 on average [6], whilst in the present study, post-LASIK eyes display LDI values 1.93 times higher on average than non-surgical eyes. It must be noted that some earlier studies using this methodology have indicated LDI (formerly halo disturbance index HDI) by the ratio of the area not seen over the total area (values from 0 to 1), while some others have done so as a percentage of the total area (0 to 100%). Currently, the system obtains the percentage area not seen by the patient. This must be taken into account when comparing results between studies. It must be also taken into account that there has been some divergence with regard to the criteria to define disturbance index and the setup used in the systems in previous reports compared to this one. Jimenez et al. [19] used a CRT screen with projection of central stimulus and peripheral stimuli on the screen. Conversely, the device used by Villa et al. [6] used a central LED, while the peripheral stimuli were the same as in the original setup. The surprising result is the difference between our results here and those reported by Villa et al. [6]. Despite different numbers, the relative increase in disturbance after LASIK remains similar (0.32 to 0.39, or a 2.16-fold increase, compared to 0.89 to 1.72, or a 1.96-fold increase).

Closer inspection of the results of straylight measurement revealed that retinal straylight measures increased by 0.07 units on average in operated eyes, which is just within the reported repeatability of the instrument, thus justifying the absence of statistical significance with regard to differences between clinical and control arms [10, 20]. Furthermore, retinal straylight showed a higher correlation with visual acuity than light distortion index measured with the Starlights. This is not unexpected, because visual acuity is obtained under photopic conditions as retinal straylight, while mesopic conditions are simulated to obtain luminous distortion index.

Both retinal straylight and luminous distortion reveal different but marginally related aspects of optical quality of the optical media of the eye. While retinal straylight essentially manifests changes in the transparency of the ocular media [15, 21], luminous distortion is more related to the changes in the optical profile of the ocular surfaces,

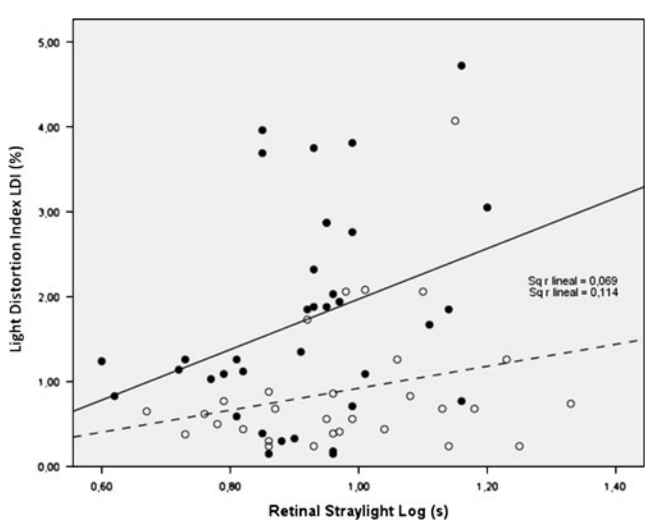

Fig. 3 Linear regression for halo distortion index (% LDI) against retinal straylight Log(s) for both groups examined: non-surgical eyes (*empty bins*, *dashed line*) and post-surgery eyes (*full bins* and *solid line*)

leading to a multifocal effect that limits vision in certain areas of the visual fields surrounding a source of light. Different modes of higher order aberrations have been identified as being correlated with the luminous disturbance index [6]. However, luminous distortion is not immune to changes in ocular media transparency. This could be the marginal link between both parameters, and the reason why both parameters are more correlated in operated eyes. Although significant haze has been carefully excluded, some extent of subtle loss of transparency after surgery could occur without notice by the clinician, being the reason why retinal straylight increases, although the sample size does not warrant enough power to detect significant differences. Following this reasoning, the increase in luminous distortion could be to some extent due to the changes within the "bulk of the cornea" in terms of transparency, while the remaining "most" disturbance effect will be due to the change in the optical profile of the cornea from prolate cornea (negative spherical aberration, partially compensating for the internal positive spherical aberration of the eye) to oblate cornea (positive spherical aberration adding to the internal) [22].

Furthermore, the role of examination conditions might be critical, since the two measurement techniques are set under opposite illumination conditions (photopic vs scotopic). While the Starlights system measures halo disturbance under 0.054 cd/m [2], mesopic level, the C-Quant straylightmeter determines disability glare under essentially photopic conditions.

In summary, both retinal straylight and luminous disturbance are somewhat correlated, but in a weak manner in normal eyes and to a higher extent in post-LASIK eyes. A larger sample population should be analyzed before and after surgery in a longitudinal way to clarify these interesting findings.

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