Double-pass technique and compensation-comparison method in eyes with cataract

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PURPOSE: To clinically assess the objective scatter index (OSI) obtained from double-pass images and the log(s) parameter measured with the direct compensation-comparison psychophysical technique in eyes with cataract.

SETTING: Ophthalmology Service, Terrassa Hospital, Barcelona, Spain.

DESIGN: Prospective observational case series.

METHODS: The analysis comprised eyes diagnosed with nuclear, cortical, or posterior subcapsular cataracts and healthy eyes (control group). Patient examinations included assessment of the manifest subjective refraction, corrected distance visual acuity, contrast sensitivity, and cataract grade using the Lens Opacities Classification System III (LOCS III) score. The protocol also included the straylight (log[s]) measured by the C-Quant device, measurement of the objective optical quality (Strehl ratio and modulation transfer function cutoff frequency), and the OSI (HD Analyzer).

RESULTS: Significant correlations with LOCS III classification were found in terms of log(s) and OSI, although they were slightly stronger with OSI for all cataract types, which could be attributable to higher-order aberrations. The OSI and log(s) shared approximately 44% of the scattering estimation and to coincide on the visual function decline with scattering for the 3 cataract types evaluated. Limits to discriminate between healthy and cataractous eyes and sensitivity and specificity values were 1.15 (sensitivity 91%, specificity 100%) for log(s) and 1.18 (sensitivity 89%, specificity 100%) for OSI ($P < .05$).

CONCLUSIONS: Both instruments provide complementary information to diagnose cataracts and follow patients. Although backscattered light from deeper retinal layers can have an effect on OSI, the double-pass image provides information to grade different types of cataract when assessing cataractous eyes for treatment.

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Intraocular scattering is an important cause of visual function impairment in eyes with cataract. Patients with cataract often report glare and contrast loss before a decrease in visual acuity manifests. Several approaches for measuring disability glare have been considered.[1] One of the first methods proposed was the measurement of the contrast sensitivity function with and without a glare source.[2] In contrast, the brightness acuity test evaluates visual acuity.[3] Other psychophysical testing tools to evaluate straylight have also been developed recently. Examples include systems for the assessment of the visual discrimination capacity in which the subject's task consists of detecting luminous peripheral stimuli around a central high-luminance stimulus over a dark background, from which a disturbance index is computed,[4] or a brightness comparison method based on a haploscopic arrangement that allows one to determine the brightness reduction of a test when there is a steady glare source in the visual field.[5]

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In recent years a new commercial straylight meter (C-Quant, Oculus Optikgeräte GmbH) has gained acceptance for controllable assessment of straylight in the clinical setting.[6–9] It is based on the so-called compensation-comparison method, which uses a central test field divided into half fields, 1 with and 1 without counterphase compensation light. The subject's task is a forced-choice comparison between the 2 half fields to decide which 1 flickers more intensely. From these measurements, a psychometric function is fitted to the subject's responses and is used to determine the straylight compensation level log(s) on the basis of a few stimuli responses. This method is an improved version of the direct-comparison method,[10] in which a ring-shaped glare source produces straylight on a dark background test field, which is lit by some of the light scattered by the lens and other parts of the eye and is thus projected on the part of the retina onto which the test field projects. This straylight is sequentially compared with the luminance of a stimulus in the same test region. Investigators have used this instrument to evaluate straylight in eyes with different optical conditions, such as different cataract morphologies[11] and eyes having laser peripheral iridotomies.[12]

In addition to the preceding psychophysical techniques, which capture the effect of forward scattering in vision, attempts to objectively assess the retinal scattered light, allowing cataract classification, have also been made. In this context, the most widespread technique is the Lens Opacities Classification System III (LOCS III),[13] which involves the observation of the lens through a slitlamp from which a gradation of the state of every cataract is assessed. The LOCS III provides information related to the back-scattered light but not to forward scattering, which is responsible for the degradation of vision. Moreover, the results might show variability between physicians.[14] To overcome this, other approaches that use Scheimpflug images[15] and optical coherence tomography[16] have been proposed, and studies conclude that they can help characterize grades of cataract from a density or anatomic point of view, although not from a functional one.

On the other hand, the double-pass technique is an objective procedure used in clinics to assess the ocular optical quality that was intended to capture the complete optical information of the eye, including the effect of higher-order aberrations (HOAs) and intraocular scattering restricted to a small visual angle.[17] Combined analysis of double-pass images and subjective measurements was proposed some years ago by Westheimer and Liang[18] to evaluate diffusion of light in the eye, although the contribution of aberrations was not considered and the procedure was not applied in eyes in which scatter was the main cause of degraded vision. A commercial instrument based on the double-pass technique is currently available (HD Analyzer, Visiometrics SL), and its clinical use is becoming more generalized.[19–22] It computes an objective scatter index (OSI),[23] which is a dimensionless parameter based on the relative intensity divided by 10 between the central area within 1 minute of arc and a peripheral ring between 12 minutes and 20 minutes of arc of the double-pass image of the eye. The OSI is limited to the measurement of the central part of the point-spread function (PSF) and therefore is susceptible to the effect of lower-order aberrations and HOAs.[24,25] However, a study by Artal et al.[23] suggests that the correction of defocus and astigmatism with a precision greater than 1.00 diopter (D) might be enough to grade scattering in eyes with cataract. In other situations in which sphere and cylinder are imprecisely corrected or HOAs play an important role, the OSI might be misleading.

The 12-to-20 minute ring is affected by the artifact of infrared light diffusion in the choroid, which can be considered a relatively constant background.[24,25] Because infrared light penetrates easily into the choroid, where diffusion and back reflection occur, this artifact is added to the recorded image; however, the use of near-infrared light (780 nm) in the double-pass imaging device increases the patient's comfort during image acquisition. Alternatives have been recently proposed[26] to overcome the limitation of registering back reflection from the choroid by using a modified double-pass system that includes an extended green light source of 530 nm $\pm$ 30 (SD). This system provides wide-angle PSF of the human eye up to 8 degrees by reconstructing the PSF from double-pass images obtained with disks of uniform radiance. This might allow new methods to evaluate the scatter at PSF angles wider than 1 degree, at which point the evaluation of scatter is unlikely to be influenced by reflection from the deep choroid. A different

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part of the pupil is also used for projection (first pass) and recording (second pass) so that backscattering from the cornea and the lens is removed from the recorded retinal images. Although it has been considered that a minimum 6.0 mm iris opening is required, and thus pupil dilation might be necessary, a clinical device incorporating this technology is not yet available.

In this study, clinical measurements were performed using the 2 mentioned available commercial instruments; that is, the C-Quant straylight meter and the HD Analyzer double-pass imaging systems. The analysis was performed with a large number of eyes with 1 of 3 different cataract morphologies (nuclear, cortical, and posterior subcapsular) and included a control group. A quantitative comparison between the log(s) provided by the straylight meter system and the OSI given by the double-pass imaging device was performed. In addition, we compared these results with those obtained using more conventional subjective procedures, such as LOCS III grading and contrast sensitivity measurements, and with objective optical quality parameters given by the double-pass imaging device related to the modulation transfer function (MTF) of the eye.

PATIENTS AND METHODS

This prospective observational cross-sectional nonconsecutive case series comprised patients with different morphology and grades of cataract. For individuals who had bilateral cataract, only 1 eye (right or left) was randomly selected, respecting the best proportionality of the different grades of cataract (especially for extreme values). Eyes of healthy subjects were used as a control group.

The study was performed at the Hospital de Terrassa, Barcelona, Spain, from September 2013 to May 2014 under supervision of 2 ophthalmologists (M.A.A., L.A.C.). After receiving a written and verbal explanation on the nature of the study, patients provided written informed consent. The study was approved by an ethical committee and conformed to the tenets of the Declaration of Helsinki of 1975, as revised in Tokyo in 2004.

Patients with a history of ocular pathology, except cataract, and surgery were excluded. All patients had a clinical evaluation for determining the manifest refractive error, corrected distance visual acuity (CDVA) with a Bailey-Lovie chart, and contrast sensitivity function with the CSV-1000E test (VectorVision, Inc.) at frequencies of 3, 6, 12, and 18 cycles per degree (cpd) measured under mesopic conditions. Cataracts were graded at the slitlamp, and the pupil was dilated by instilling 0.2 mL of tropicamide 1.0%. The grading was according to the LOCS III[13] and based on nuclear opalescence (NO1, NO2, NO3, NO4), cortical cataracts (C1, C2, C3), and posterior subcapsular cataracts (P1, P2, P3, P4). Mixed cataracts with more than 1 morphologic type were excluded. Mixed cataracts were considered when they had 2 gradations (NO, C, or P) greater than 1, or alternatively when they had 2 or more gradations of 1 (NO, C, or P). No patient had a cortical cataract of grade C4 with NO or P less than 2. An independent classification was performed by both an ophthalmologist and an optometrist. The results matched in most cases, and in case of disagreement, the grading was reviewed by the same ophthalmologist.

The protocol included the assessment of straylight measured by the C-Quant straylight meter. Higher values of log(s) indicate more straylight and more sensitivity to glare. This test also gives an assessment of the reliability of the test outcome, specified as the expected standard deviation (SD) of the individual measurement value if repeated measurements (expected SD) and Q occur, which is a further quality criterion. According to the manual of the instrument, if the expected SD is less than 0.08 and Q is more than 1, the reliability of the result is considered good. If the expected SD is less than 0.08 and Q is more than 0.5, the reliability is considered acceptable. A warning is given if the expected SD is more than 0.08 or Q is less than 0.5. Eyes with outcomes fulfilling this last condition were excluded from analysis in this study. The test was performed without pupillary dilation.

For a quantitative measurement of the optical quality, the Strehl ratio was considered. This parameter is commonly used for estimating the overall optical quality that is defined in the HD Analyzer double-pass imaging device as the ratio between the MTF area of the eye and the diffraction-limited MTF area. The MTF represents the contrast loss resulting from the ocular optics on a sinusoidal grating as a function of its spatial frequency. The Strehl ratio ranges from 0 to 1. A lower value indicates there is a greater contribution of aberrations and therefore poorer optical quality. The MTF cutoff frequency, which corresponds to the largest spatial frequency (in cpd) that can be resolved in the retina at maximum contrast, was also assessed. In the double-pass imaging device, it is defined as the cutoff frequency corresponding to a 0.01 MTF value because there is background noise in the profile computed from the real recorded double-pass image and the zero value cannot be reached.

The OSI was measured using the double-pass instrument. In this case, measurements were also performed without dilation and with a pupil diameter of 4.0 mm. Because optical quality might be dependent on tear-film quality, measurements were taken just after the patient blinked.[27] The spherical refractive error was automatically corrected by the double-pass system (from −8.00 to +6.00 D with an accuracy of 0.06 D), whereas astigmatism was corrected with an external cylindrical lens (with an accuracy of 0.25 D) to obtain the best possible retinal image.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows software (version 20, SPSS, Inc.). A *P* value less than 0.05 was considered statistically significant. The Kolmogorov-Smirnov test was used to evaluate the normal distribution of variables. The Mann-Whitley *U* test for nonparametric variables and an independent sample *t* test for parametric variables were used to compare the mean between different cataract types and between them and the control group. Analysis of variance (ANOVA) was used to test whether the differences in CDVA, contrast sensitivity, log(s), Strehl ratio, MTF cutoff frequency, and OSI between grades of cataract scored with LOCS III were statistically significant. It was also used for log(s) and OSI to establish significant differences between cataract types (ie, nuclear, cortical, and posterior subcapsular).

In addition, the validity of log(s) and the OSI with respect to optical quality (Strehl ratio and MTF cutoff frequency) and

Table 1. Patient demographics and subjective refraction SE.

Parameter	Cataract Group	Control Group
Sex (n)		
Male	43	4
Female	35	6
Eyes (n)		
Right	37	4
Left	41	6
SE (D)		
Mean ± SD	0.44 ± 2.36	−0.47 ± 1.24
Range	−5.50, 5.75	−2.20, 1.25

SE = spherical equivalent

psychophysical vision quality tests (CDVA and contrast sensitivity) was studied to avoid bias of age in the results by using the Pearson partial correlation coefficient (*r*), controlling for age.

Agreement between log(s) and the OSI was also analyzed using a linear regression and a Pearson partial correlation coefficient, controlling for age, for the different cataract types.

Finally, the area under the receiver operating characteristic (ROC)[28] plot was used to quantify the diagnostic accuracy of log(s) and the OSI between the cataract group and the control group. The maximum Youden index (J)[29] was considered as the cutoff point to classify healthy eyes and cataractous eyes, and the corresponding specificity and the sensitivity[30] were calculated. The Youden index (J = Sensitivity + Specificity – 1) is seen to be equal to the sum diminished by unity of the 2 fractions, showing the proportions correctly diagnosed for the cataract group and control group.

RESULTS

Of the 112 patients with cataract, 14 patients were excluded because of the absence of reliable straylight meter values, 10 because of the presence of mixed cataract types, 6 because they did not meet the inclusion criterion for spherical equivalent (SE), and 4 because of a lack of correct images with the double-pass imaging. Thus, 78 cataractous eyes of 78 patients and 10 healthy eyes of 10 patients were included in the study. Table 1 shows the patient demographics and the subjective refraction in each group.

Eye and sex distribution occurred with equal probability in the whole cohort and in the different cataract groups. There were no significant differences in SE between the 3 types of cataract or between them and the control group, although the range of values was greater in the cataract group.

Table 2 shows the mean age distribution of the sample. The Student *t* test did not yield a statistically significant difference in age between the 3 types of cataract, although it did so between the control group and the whole cataract group ($t = 7.765$, $P < .001$).

In comparing the means between the whole cataract group and the control group, difference was significant

Table 2. Age distribution in the cohort by type and grade of cataract.

		Age (Y)	
Patients	LOCS III Score (n)	Mean ± SD	Range
Cataract group			
NUC total	35	70 ± 9	47, 86
NO1	8	74 ± 6	67, 85
NO2	13	67 ± 10	47, 83
NO3	9	68 ± 9	55, 86
NO4	5	74 ± 5	68, 81
COR total	18	69 ± 6	57, 79
C1	3	67 ± 6	62, 74
C2	8	68 ± 7	57, 79
C3	7	71 ± 4	66, 77
PSC total	25	69 ± 9	47, 85
P1	4	64 ± 5	57, 69
P2	10	73 ± 11	57, 85
P3	8	69 ± 10	47, 79
P4	3	68 ± 4	64, 71
Control group	10	58 ± 4	52, 65

COR = cortical cataract; LOCS III = Lens Opacities Classification System III; NO = nuclear opalescence; NUC = nuclear cataract; PSC = posterior subcapsular cataract

for CDVA ($t = -6.676$, $P < .001$), contrast sensitivity at 3 cpd ($t = 2.210$, $P = .030$), at 6 cpd ($t = 2.748$, $P = .007$), and at 12 cpd ($t = 2.574$, $P = .012$), log(s) ($t = -9.545$, $P < .001$), Strehl ratio ($t = 4.888$, $P < .001$), MTF cutoff frequency ($t = 8.493$, $P < .001$), and OSI ($t = -10.418$, $P < .001$); however, it was not statistically significant for contrast sensitivity at 18 cpd ($t = 1.116$, $P = .268$).

When comparing the 3 types of cataract (Table 3), no statistically significant difference ($P > .05$) was found in the CDVA, contrast sensitivity, log(s), Strehl ratio, MTF cutoff frequency, or OSI. Although the maximum LOCS III degree of cortical cataracts was lower (ie, C3), cortical cataracts showed the worst mean CDVA, Strehl ratio, and MTF cutoff frequency.

Table 4 shows the mean values for the variables grouped following the LOCS III classification scale. As expected, the log(s) and OSI values increased with cataract severity grade and all the other parameters related to optical quality and vision quality decreased. The ANOVA between the LOCS III score classification groups showed statistically significant differences for CDVA (F = 18.3, $P < .001$), contrast sensitivity at 3 cpd (F = 2.7, $P = .035$), contrast sensitivity at 6 cpd (F = 7.4, $P < .001$), contrast sensitivity at 12 cpd (F = 6.5, $P < .001$), contrast sensitivity at 18 cpd (F = 3.9, $P = .005$), log(s) (F = 21.4, $P < .001$), Strehl ratio (F = 17.1, $P < .001$), MTF cutoff frequency (F = 20.4, $P < .001$), and OSI (F = 37.3, $P < .001$).

In the 3 types of cataract, the ANOVA for parameters log(s) and OSI between the LOCS III classification

Table 3. Mean ± SD for the parameters studied.

Parameter	Control Group	Cataract Group		
		NUC	COR	PSC
Psychophysical				
CDVA (logMAR)	−0.10 ± 0.12	0.21 ± 0.29	0.25 ± 0.16	0.24 ± 0.33
CS 3 cpd	1.69 ± 0.12	1.47 ± 0.31	1.48 ± 0.33	1.49 ± 0.26
CS 6 cpd	1.92 ± 0.19	1.61 ± 0.33	1.68 ± 0.30	1.65 ± 0.31
CS 12 cpd	1.51 ± 0.20	1.19 ± 0.33	1.26 ± 0.36	1.23 ± 0.37
CS 18 cpd	0.93 ± 0.27	0.83 ± 0.31	0.85 ± 0.33	0.74 ± 0.42
log(s)	1.09 ± 0.08	1.49 ± 0.26	1.43 ± 0.29	1.45 ± 0.26
Double-pass				
SR	0.20 ± 0.04	0.11 ± 0.05	0.09 ± 0.03	0.11 ± 0.09
MTF cutoff (cpd)	39.6 ± 6.3	16.2 ± 10.2	11.92 ± 8.0	12.7 ± 8.1
OSI	0.67 ± 0.18	4.19 ± 3.12	4.28 ± 2.12	5.20 ± 3.99

CDVA = corrected distance visual acuity; COR = cortical cataract; cpd = cycles per degree; CS = contrast sensitivity; MTF = modulation transfer function; NUC = nuclear cataract; OSI = objective scatter index; PSC = posterior subcapsular cataract; SR = Strehl ratio

groups showed statistically significant difference ($P < .05$), being the highest for the OSI in nuclear cataracts ($F = 40.367$), followed by cortical cataracts ($F = 36.719$) and subcapsular cataracts ($F = 12.682$). Although for log(s), the highest difference was also for nuclear cataracts ($F = 21.013$), it was followed by the subcapsular group ($F = 13.059$) and then the lowest one being for the cortical group ($F = 9.055$). Figure 1 shows log(s) and OSI for the 3 types of cataract.

Figure 2 shows a comparison of log(s) and OSI. These 2 parameters share approximately 44% of the scattering estimation when considering the entire cohort. Pearson correlations between these 2 parameters were moderate and statistically significant for the 3 types of cataract ($P < .001$), being slightly higher in the nuclear cataract group ($r = 0.694$, n = 35) followed by the cortical cataract group ($r = 0.693$, n = 18) and the posterior subcapsular cataract group ($r = 0.673$, n = 25).

Table 5 shows the partial correlations (r), controlling for age, of log(s) and OSI with CDVA, contrast sensitivity, MTF cutoff frequency, and Strehl ratio. Both log(s) and OSI performed in a similar way, although OSI correlation values were stronger in all cases; this was expected because the latter is computed by considering that the peak of the PSF, and thus the presence of ocular aberrations, especially the HOAs that have not been corrected, might influence it.

There were differences in this relationship depending on the type of cataract. For nuclear cataracts, strong correlations were observed with the CDVA, contrast sensitivity at intermediate frequencies, Strehl ratio, and MTF cutoff frequency. Specifically, the OSI had a stronger correlation with contrast sensitivity at 6 cpd than with

Table 4. Mean ± SD for the parameters studied.

Parameter	LOCS III Score (NUC, COR, or PSC)			
	1 (n = 15)	2 (n = 31)	3 (n = 24)	4 (n = 8)
Psychophysical				
CDVA (logMAR)	0.03 ± 0.16	0.18 ± 0.20	0.31 ± 0.30	0.59 ± 0.25
CS 3 cpd	1.56 ± 0.28	1.52 ± 0.27	1.43 ± 0.34	1.31 ± 0.23
CS 6 cpd	1.81 ± 0.25	1.70 ± 0.31	1.57 ± 0.30	1.30 ± 0.19
CS 12 cpd	1.41 ± 0.28	1.29 ± 0.28	1.12 ± 0.41	0.90 ± 0.21
CS 18 cpd	0.99 ± 0.24	0.81 ± 0.36	0.80 ± 0.34	0.46 ± 0.31
log(s)	1.22 ± 0.22	1.43 ± 0.22	1.55 ± 0.20	1.83 ± 0.15
Double-pass				
SR	0.16 ± 0.10	0.10 ± 0.04	0.07 ± 0.02	0.06 ± 0.02
MTF cutoff (cpd)	23.9 ± 8.4	15.5 ± 8.4	8.9 ± 5.1	5.7 ± 4.5
OSI	1.56 ± 0.99	3.47 ± 1.63	5.88 ± 2.52	10.23 ± 3.69

CDVA = corrected distance visual acuity; COR = cortical cataract; cpd = cycles per degree; CS = contrast sensitivity; LOCS III = Lens Opacities Classification System III; MTF = modulation transfer function; NUC = nuclear cataract; OSI = objective scatter index; PSC = posterior subcapsular cataract; SR = Strehl ratio

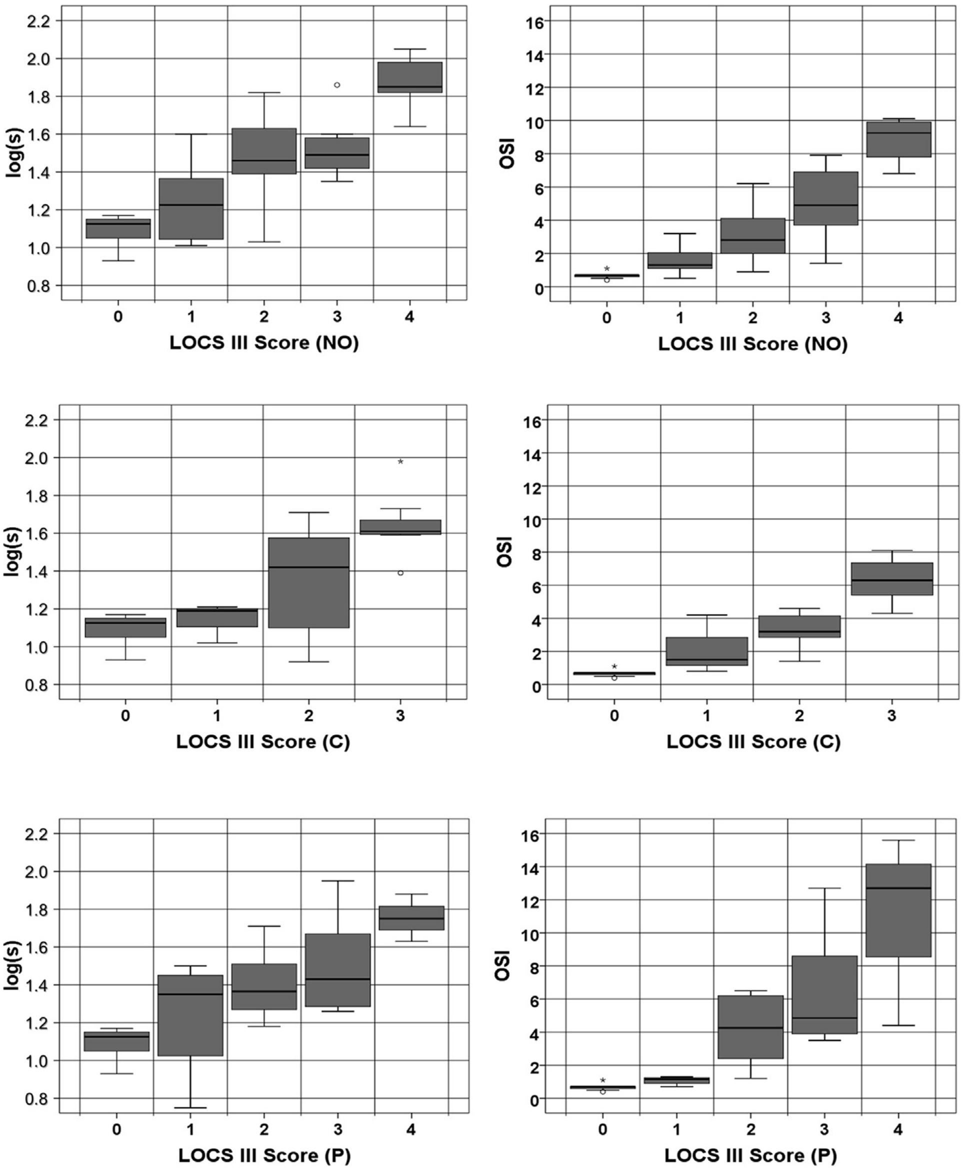

Figure 1. Boxplots showing log(s) and the OSI values for eyes with nuclear cataracts graded as NO1, NO2, NO3, and NO4 (*top*), cortical cataracts graded as C1, C2, and C3 (*middle*), and posterior subcapsular cataracts graded as P1, P2, P3, and P4 (*bottom*) and the control group. The following 5 statistical descriptors are shown in these plots: maximum, third quartile, median, first quartile, and minimum, as well as the outliers (C = cortical cataract; LOCS III = Lens Opacities Classification System III; NO = nuclear opalescence; P = posterior subcapsular cataract).

CDVA. For cortical cataracts, both log(s) and the OSI had a much stronger correlation with objective parameters related to optical quality than with psychophysical parameters; however, the correlation with log(s) was stronger at lower frequencies (contrast sensitivity 3 cpd), whereas with the OSI it was stronger at medium frequencies (contrast sensitivity 12 cpd). Moderate correlations were observed in both cases with CDVA. For posterior subcapsular cataracts, correlations were strong between log(s) and the OSI and MTF cutoff frequency, although not as strong with the Strehl ratio. In general, there was also a close association between log(s) and the OSI and contrast sensitivity at all frequencies. In particular, the OSI had a stronger correlation with contrast sensitivity at medium and high frequencies (6, 12, or 18 cpd) than with CDVA.

In the entire cohort (cataract group and control group), the area under the ROC curve was 0.909 (95% confidence interval [CI], 0.847-0.970) for log(s), 0.980 (95% CI, 0.953-1.000) for the OSI, 0.830 (95% CI, 0.790-0.894) for the Strehl ratio, and 0.897 (95% CI, 0.820-0.920) for the MTF cutoff frequency. This represents the probability for a randomly selected eye from the cataract group to have a higher OSI value than a randomly selected eye from the control group. Because the OSI provided a larger area under the ROC curve than the Strehl ratio and MTF cutoff frequency parameters, the same analysis was repeated to evaluate separately the 3 types of cataract in terms of OSI and log(s). For nuclear cataracts, the area under the ROC curve was 0.911 (95% CI, 0.824-0.999) and 0.970 (95% CI, 0.920-1.000) for log(s) and OSI,

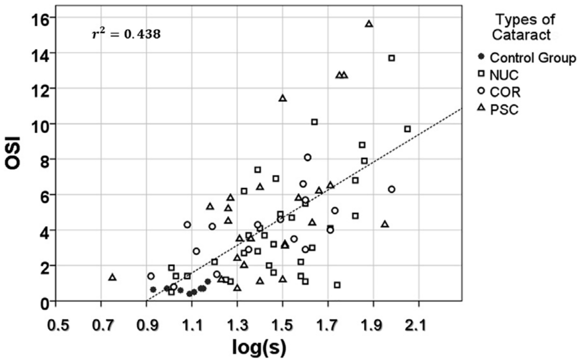

Figure 2. Scatterplot for log(s) and the OSI. Dotted line = linear regression (COR = cortical; OSI = objective scatter index; NUC = nuclear; PSC = posterior subcapsular).

respectively; for cortical cataracts, it was 0.833 (95% CI, 0.677-0.990) and 0.994 (95% CI, 0.977-1.000), respectively; and for posterior subcapsular cataracts, it was 0.984 (95% CI, 0.950-1.000) and 0.960 (95% CI, 0.883-1.000), respectively.

Using the maximized Youden index as the limit value to discriminate between healthy eyes and cataractous eyes in terms of both log(s) and the OSI, the study found the following values: 1.15 (sensitivity 91%, specificity 100%) for log(s) and 1.18 (sensitivity 89%, specificity 100%) for the OSI. The results for each cataract type were slightly different. In nuclear cataracts, they were 1.15 (sensitivity 89%, specificity 100%) for log(s) and 1.19 (sensitivity 89%, specificity 100%) for the OSI. In cortical cataracts, they were 1.25 (sensitivity 94%, specificity 100%) and 1.18 (sensitivity 79%, specificity 100%), respectively; and in posterior subcapsular cataracts, they were 1.15 (sensitivity 92%, specificity 100%) and 1.18 (sensitivity 96%, specificity 100%), respectively.

Both parameters showed a high ability to discriminate between cataractous eyes and healthy eyes for every cataract type. Sensitivity values were similar except for cortical cataracts, for which the OSI showed a higher sensitivity than log(s). As expected in a cataractous population, both parameters showed a very high specificity (100%). The most important difference between the OSI and the log(s) is that the OSI is calculated from the PSF, specifically taking into account the intensity recorded between 12 to 20 minutes of arc and that of the peak. Therefore, depending on the particular pattern of HOAs present in an eye, the OSI might change.

DISCUSSION

The following classification was established for the OSI parameter based on the results obtained for 38 eyes with diagnosed nuclear cataracts[23]: Values below 1 correspond to normal eyes with low amounts of scatter; between 1 and 3, to older eyes with associated scatter of an early cataract; between 3 and 7, to developed cataract that should have surgery; and higher than 7, to eyes with severe cataract. This classification was later used in 188 eyes with nuclear, cortical, and posterior subcapsular cataracts, obtaining consistent results.[31] The OSI values obtained in this study according to LOCS III classification[13] are consistent with those previously published.

A European drivers study[11] proposed 1.4 log(s) as a safe limit for driving; this would correspond to cataracts with a LOCS III score lower than 2 in our study. This suggests that the OSI safe margin for driving is approximately 3.

Although both log(s) and OSI are related to scattering, there are significant differences between the 2 instruments because they are based on different

Table 5. Partial correlations (*r*), controlling for age, between log(s) and the OSI.

	Log(s)			OSI		
Parameter	NUC	COR	PSC	NUC	COR	PSC
Cataract group (n)	35	18	25	35	18	25
Psychophysical						
CDVA (logMAR)	0.581*	0.331	0.528*	−0.404*	−0.375	−0.477*
CS 3 cpd	−0.273	−0.325	−0.441*	−0.560*	−0.219	−0.652*
CS 6 cpd	−0.460*	−0.275	−0.514*	−0.453*	−0.455*	−0.682*
CS 12 cpd	−0.497*	−0.151	−0.503*	−0.393	−0.153	−0.635*
CS 18 cpd	−0.233	−0.249	−0.482*	−0.404*	−0.375	−0.477*
Optical quality						
SR	−0.614*	−0.568*	−0.328	−0.759†	−0.757†	−0.549*
MTF cutoff (cpd)	−0.635*	−0.544*	−0.656*	−0.762†	−0.780†	−0.726†

CDVA = corrected distance visual acuity; COR = cortical cataract; cpd = cycles per degree; CS = contrast sensitivity; MTF = modulation transfer function; NUC = nuclear cataract; OSI = objective scatter index; PSC = posterior subcapsular cataract; SR = Strehl ratio
**r* from 0.4 to 0.69
†*r* from 0.7 to 0.9

principles. The most important is that the OSI is calculated from the PSF, specifically taking into account the intensity of the central part of the PSF. Therefore, it is susceptible to artifacts related to the effect of aberrations and backscattered light. It is also important to highlight the effect that backscattered light from deeper retinal layers can have on the double-pass image, and thus on the OSI. The results in this study are in accordance with those in previous studies[23,31] that found good correlations between the OSI and the LOCS III classification system in eyes with cataract.

The OSI parameter was measured using a constant 4.0 mm exit pupil for the whole procedure, whereas log(s) was measured using the individual's natural pupil. Another aspect to consider, especially when it comes to older persons, is that log(s) requires more active participation by the individual.

The disagreement between the 2 parameters, regardless of the individual's participation, could also be caused by the scattering provided by the HD Analyzer double-pass imaging device, which unlike the C-Quant straylight meter is for a specific 780 nm wavelength. Another aspect to consider is that the scatterplot comparing log(s) with the OSI showed that the greatest differences between the 2 parameters were in eyes with high scattering levels.

However, there was correlation between visual function deterioration caused by the different types of cataract and the log(s) and the OSI parameters, enabling one to differentiate between healthy eyes and cataractous eyes in a similar way with cutoff values of 1.18 for the OSI and 1.15 for log(s). It is noteworthy that the mean age in the group of patients with cataract was slightly higher than that in the control group. Both instruments also provide a similar clinical classification of cataractous patients regardless of the cataract type.

Visual function in terms of CDVA and contrast sensitivity is affected differently by intraocular scattering if the cataract type is considered. Similar to what other studies have reported for the same intraocular scattering value, contrast sensitivity deteriorates the most in posterior subcapsular cataracts.[32] On the other hand, nuclear cataracts show a more linear contrast sensitivity deterioration than cortical cataracts. It has also been found that although there is a moderate correlation between scattering and CDVA in posterior subcapsular and nuclear cataracts, the correlation is much weaker in cortical cataracts. Moreover, there is a weak correlation between intraocular scattering and Strehl ratio for posterior subcapsular cataracts, especially for log(s), whereas this correlation is much stronger for nuclear cataracts, and especially for cortical cataracts. The morphology of cortical cataracts, which advances from the periphery of the lens toward the center, is likely to affect optical quality more rapidly and strongly than contrast sensitivity, contrary to what occurs with posterior subcapsular cataracts in which contrast sensitivity in general decreases because of intraocular scattering.

In conclusion, log(s) and OSI were useful parameters in studying the effect of intraocular scattering on visual impairment and providing important complementary information to diagnose cataract types to allow proper follow-up. Correlations with the LOCS III classification are found in both cases, although they were slightly stronger with the OSI for all cataract types.

In addition, contrast sensitivity was affected the most in eyes with posterior subcapsular cataracts, whereas optical quality was most affected in eyes with cortical cataracts. The latter suggests a higher presence of HOAs, although this could not be confirmed in our study.

Cortical cataract has a less of an effect on visual function deterioration as scattering increases. Nevertheless, it would be interesting to assess the optical quality deterioration caused by scattering in eyes with cortical cataracts in a larger cohort, and evaluate how it affects other aspects such as night vision, double vision, and halos.

WHAT WAS KNOWN

- There is no established scale to assess the visual effect of cataract types, and the subjectivity of some tests adds a high variability between individuals.

WHAT THIS PAPER ADDS

- Log(s) and the OSI provided useful information to use with the traditional methods regarding patient follow-up and cataract surgery management.
- The optical quality (Strehl ratio and MTF cutoff frequency) provided by the double-pass imaging device was affected the most in cortical cataracts, whereas visual function was most affected in posterior subcapsular cataracts.

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