Objective Assessment of Crystalline Lens Opacity Level by Measuring Ocular Light Scattering With a Double-Pass System

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• PURPOSE: To assess the crystalline lens opacity level by measuring ocular light scattering with a double-pass system.

• DESIGN: Prospective, single-center, cross-sectional study.

• METHODS: Two hundred fifty-three eyes of 135 patients referred for cataract evaluation were enrolled. Patients with corneal or retinal anomalies potentially impairing ocular transparency were excluded. Lens opacification was assessed by the Lens opacities classification system III. Optical Quality Analysis System (Visiometrics SL) measurements provided ocular Modulation Transfer Function cutoff frequency and Objective Scatter Index. Best-corrected visual acuity and Quality of Vision questionnaire scores (Rasch-scaled) were recorded. We analyzed correlations between visual acuity, type and severity of cataract, Optical Quality Analysis System measurements, and discomfort level in each group.

• RESULTS: In patients with best-corrected visual acuity better than 20/32, we found correlations between Objective Scatter Index, Modulation Transfer Function, and visual acuity ($r = 0.4$, $P < .0001$). The Objective Scatter Index, Modulation Transfer Function, and visual acuity were correlated with each type of cataract. In patients with good visual acuity and moderate functional symptoms, the Objective Scatter Index values also were correlated to the severity of posterior subcapsular cataract ($r = 0.4$, $P = .0006$).

• CONCLUSIONS: Patients with incipient cataract may report visual discomfort, despite minor lens opacity on slit-lamp examination, minor loss of best-corrected visual acuity, or both. The measurement of ocular scattering with the Optical Quality Analysis System device may be a useful tool in the preoperative evaluation of patients with early cataract. (Am J Ophthalmol 2013;■: ■–■. © 2013 by Elsevier Inc. All rights reserved.)

T O SATISFY THE INCREASING QUEST FOR BETTER postoperative results and to reduce postoperative spectacle dependency, there have been significant developments in phacoemulsification, intraocular lens (IOL) designs, and IOL power formulae over the past decade. Hence, cataract surgery is performed at earlier and earlier stages in the disease progression in eyes with clearer crystalline lenses and relatively preserved visual acuity.

The Optical Quality Analysis System (Visiometrics SL, Terrassa, Spain) is the only currently clinically available device that quantifies the combined effect of optical aberrations and light scatter resulting from the loss of ocular transparency in the human eye. This double-pass system performs these measurements by recording the retinal image of a point source of light obtained after focalization of an infrared signal. The retinal image corresponds to the double-pass point spread function, which enables the determination of the modulation transfer function and the maximum theoretical visual acuity. The determination of the Modulation Transfer Function by a double-pass method has been used previously to investigate retinal images as a function of age, contact lens use, or implantation of IOLs.[1–4]

In this study, we evaluated, in a population of patients with cataract of varying levels of severity, the correlation between the clinical cataract classification via slit-lamp examination (Lens Opacities Classification System III), the subjective quality of vision assessed by a questionnaire (Quality of Vision questionnaire), the best-corrected visual acuity (BCVA), and the objective loss of ocular transparency as measured by the Optical Quality Analysis System device.

METHODS

• STUDY POPULATION: The data for this prospective single-center cross-sectional study were collected between January 2010 and December 2011 at the Rothschild Foundation, Paris, France. The study and data accumulation were carried out with approval from the Rothschild Foundation Institutional Review Board. Informed consent was obtained from each participant after receiving an explanation of the nature and intent of the study. Eligible subjects

were approached prospectively during cataract evaluation visits; those giving consent were enrolled consecutively.

Inclusion criteria were a diagnosis of cataract (early to mature) and the ability to speak, read, and comprehend French fluently. Patients having anomalies impairing ocular transparency, such as corneal dystrophies, corneal scars, retinal anomalies (age-related macular degeneration, retinal detachment, macular dystrophies, and so forth), were excluded. All patients with ocular, medical, or surgical history other than lens opacities, cataract suspicion, or both also were excluded.

All patients underwent a complete ocular examination including BCVA, a detailed slit-lamp biomicroscopy examination to eliminate causes of ocular transparency loss other than cataract, and a dilated fundus examination. The type and the grade of cataract were assessed by the same experienced ophthalmologist (D.G.) according to the Lens Opacities Classification System III grading system.[5] All cataracts were classified and graded in 4 groups: nuclear opacity, nuclear color, cortical opacity, and posterior subcapsular opacity. The severity of each item was graded from 1 (early cataract) to 6 (mature cataract) for the nuclear color and opacity and from 1 to 5 for the cortical and posterior subcapsular opacities.

During the preoperative evaluation, patients completed the Quality of Vision questionnaire (self-administered). This questionnaire was developed by McAlinden and associates and consists of 10 items (questions) describing 10 visual symptoms.[6] For the first 7 symptoms, an accompanying image of the specific visual symptom is displayed to aid patient understanding. Four response categories are used for each item to provide the opportunity to discriminate levels of symptoms with a low possibility of redundancy. The raw questionnaire responses were Rasch scaled to provide 3 scores of frequency, severity, and bothersome of visual symptoms. Higher scores relate to poorer quality of vision.

A different ophthalmologist (F.C.) from the one who determined the grade of cataract during the slit-lamp examination performed the Optical Quality Analysis System measurements and collected the Objective Scatter Index and Modulation Transfer Function values for each eye. To analyze the correlations between the variables, eyes were divided into different groups that were based on visual acuity, cataract type, and visual symptoms. Eyes were separated into 2 visual acuity groups (in the first group, the visual acuity was worse than 20/40 and in the second group, the visual acuity was 20/32 or better). Three cataract groups also were constituted (the nuclear cataract group, the cortical cataract group, and the posterior subcapsular cataract group). Eyes also were separated in 3 groups depending on the Quality of Vision questionnaire score: in the first group, the level of visual symptoms was low: the frequency, severity, and bothersome quality of visual symptoms were lower than 30; in the second group, visual symptoms were moderate (scores of more than 30 but less

than 60); and in the third group, visual symptoms were high, with scores of more than 60.

• DOUBLE-PASS SYSTEM: In this study, we used the clinical double-pass Optical Quality Analysis System instrument, which measures the combined effect of higher-order aberrations and scattered light, thus providing complete information of the optical quality of the patient's eye. A point source image is formed on the patient's retina using a 780-nm laser diode. We acquired double-pass images of every eye at best focus, corrected internally by an optometer that ranges from −8 to 6 diopters (D). The astigmatism also was corrected by using the appropriate cylindrical lens placed in front of the eye. Then, the light beam was focused on the retina. The reflected light passed through the diameter of the exit pupil, which was settled at 4 mm. A charge-coupled device camera recorded the double-pass images after the light was reflected on the retina and beam splitter. Pupil alignment was controlled with an additional camera. A personal computer was used to process the retinal images and to collect the data.

The double-pass instrument provides several measurements, including the Objective Scatter Index, the Modulation Transfer Function, and the maximum visual acuity predicted for objects with 100%, 50%, and 9% contrast. The Point Spread Function recorded by the double-pass system represents the image projected onto the retina from a point light source. The Point Spread Function was calculated as the mean of 6 individual acquisitions. In the absence of optical aberrations or light scattering, the Point Spread Function is quasipoint and the image perceived is unaltered (if the diffraction eventually caused by a large pupil diameter is moderate). The Modulation Transfer Function curve, directly computed from the Point Spread Function, represents the attenuation percentage of the contrast of the retinal image at various resolutions (spatial frequencies), including the combined effects of scatter and high-degree optical aberrations. The Modulation Transfer Function value is highest when the contrast in the image is the same as the contrast in the object. The value considered in this study was the cutoff point of the Modulation Transfer Function curve on the x-axis. The cutoff point represents the point at which the spatial frequency is at a maximum. The results are given in cycles per degree. For a perfect optical system without any optical aberrations, the Modulation Transfer Function curve is a straight line. The Objective Scatter Index is an objective evaluation of the scattering degree caused by the loss of transparency of one or more of the ocular structures, such as corneal opacities or cataract. This index is defined as the ratio between the integrated light in the periphery and in the surroundings of the central peak of the double-pass image. The higher the Objective Scatter Index value, the higher the level of intraocular scattering. The Objective Scatter Index values range from 0 (no scatter) to a maximum of 25 (highly scattered system). The

Objective Scatter Index parameter can be affected by uncorrected refractive errors (defocus and astigmatism). Hence, all patients had a refractive examination and all measurements were performed with best-corrected sphere and cylinder to avoid these artifacts.

• STATISTICAL ANALYSIS: Statistical analysis was performed using Stata version 10.0 for Macintosh (Apple, Cupertino, California, USA). Statistical significance was set at $P < .05$. The Quality of Vision questionnaire raw data were Rasch-scaled to provide a linear measure of quality of vision for the 3 subscales of the questionnaire. The relationship between variables was analyzed using the Spearman rank nonparametric correlation coefficient.

RESULTS

• BASELINE CHARACTERISTICS OF VISUAL ACUITY, CATARACT, AND VISUAL SYMPTOMS GROUPS: One hundred thirty-five patients were recruited and 253 eyes were included in the study. The mean age of the patients was 68.1 ± 11.1 years (range, 33 to 90 years). The mean BCVA was 0.2 ± 0.2 logarithm of the minimal angle of resolution units (range, 0 to 1.3 logarithm of the minimal angle of resolution units). The mean preoperative spherical equivalent was 0.9 ± 3.3 D (range, −10 to 6 D). The mean Objective Scatter Index value was 4.1 ± 3.5 (range 0.1 to 15.7). The mean Modulation Transfer Function cutoff value was 16.5 ± 11.5 cpd (range, 1.5 to 54.8 cpd). The descriptive statistics of all the subgroups are summarized in the Table.

• CORRELATIONS BETWEEN CRYSTALLINE LENS OPACITY LEVEL ASSESSED BY A DOUBLE-PASS SYSTEM AND SUBJECTIVE MEASUREMENTS: In the group with a visual acuity of 20/32 or better (n = 132), we found a correlation between the Objective Scatter Index value and the visual acuity ($r = 0.4$, $P < .0001$) and between the Modulation Transfer Function value and the visual acuity ($r = −0.4$, $P = .0001$). The Objective Scatter Index, Modulation Transfer Function, and visual acuity were correlated with the grade of cataract in every type of cataract considered (Figures 1, 2, and 3). The Modulation Transfer Function cutoff value, but not the Objective Scatter Index value, was correlated to the frequency, severity, and bothersome quality of visual symptoms ($r = 0.4$ and $P = .007$, $r = 0.4$ and $P = .007$, and $r = 0.4$ and $P = .007$, respectively).

In the group with a visual acuity worse than 20/40 (n = 121), we found correlations between Objective Scatter Index values and visual acuity ($r = 0.5$, $P = .0001$), frequency ($r = −0.4$, $P = .03$), severity ($r = −0.4$, $P = .03$), and bothersome quality ($r = −0.4$, $P = .03$) of visual symptoms. The visual acuity and Objective Scatter Index were correlated with the severity of
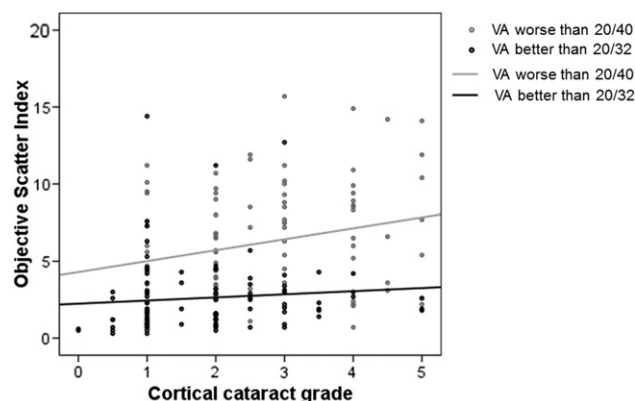

FIGURE 1. Graph showing correlations between crystalline lens opacity level assessed by a double-pass system and cortical cataract grade. The correlation coefficient between the objective scatter index and cortical cataract grade was 0.4 ($P = .04$) in patients with visual acuity (VA) better than 20/32 and was 0.5 ($P = .08$) in patients with VA worse than 20/40.
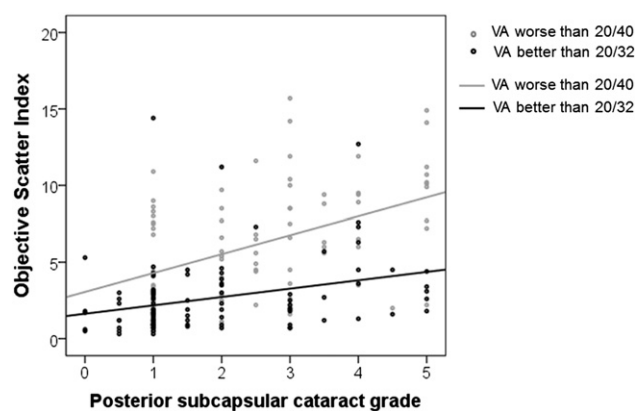

FIGURE 2. Graph showing correlations between crystalline lens opacity level assessed by a double-pass system and posterior subcapsular cataract grade. The correlation coefficient between the objective scatter index and posterior subcapsular cataract grade was 0.5 ($P = .01$) in patients with visual acuity (VA) better than 20/32 and was 0.5 ($P = .04$) in patients with VA worse than 20/40.

subcapsular posterior cataract ($r = 0.5$ and $P = .04$, and $r = 0.5$ and $P = .0001$), but not with the severity of cataract in the other cataract groups.

In the nuclear cataract group (n = 106), we found correlations between objective Scatter Index and visual acuity ($r = 0.7$; $P < .0001$) and between Modulation Transfer Function and visual acuity ($r = −0.5$; $P < .0001$). The severity of nuclear cataract was correlated with Objective Scatter Index, Modulation Transfer Function cutoff value, and visual acuity ($r = 0.5$, $r = −0.5$, and $r = 0.6$, respectively; $P < .0001$). No correlations were found between visual symptoms and Optical Quality Analysis System measurements.
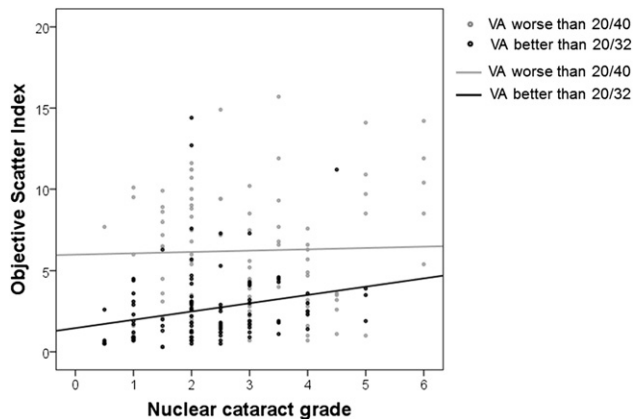
FIGURE 3. Graph showing correlations between crystalline lens opacity level assessed by a double-pass system and nuclear cataract grade. The correlation coefficient between the objective scatter index and nuclear cataract grade was 0.5 ($P = .01$) in patients with visual acuity (VA) better than 20/32 and was 0.3 ($P > .05$) in patients with VA worse than 20/40.
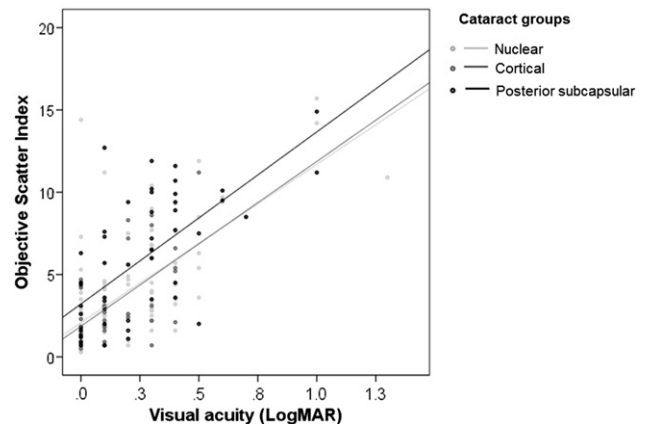

FIGURE 4. Graph showing correlations between crystalline lens opacity level assessed by a double-pass system and visual acuity in cataract groups. The correlation coefficient between the objective scatter index and visual acuity (in logarithm of the minimal angle of resolution [logMAR] units) was 0.7 ($P < .0001$) in the nuclear cataract group, 0.5 ($P = .001$) in the cortical cataract group, and 0.6 ($P < .0001$) in the posterior subcapsular cataract group.

In the cortical cataract group (n = 40), the visual acuity was correlated with the Objective Scatter Index ($r = 0.5$, $P = .001$), Modulation Transfer Function ($r = -0.6$, $P = .0003$), the grade of cortical cataract ($r = 0.6$, $P = .0001$), and the frequency, severity, and bothersome quality of the visual symptoms ($r = 0.4$ for each item and $P = .007$, $P = .009$, and $P = .009$, respectively). No correlations were found between the Optical Quality Analysis System measurements and the visual symptoms.

In the posterior subcapsular cataract group (n = 53), Objective Scatter Index was correlated with visual acuity ($r = 0.6$, $P < .0001$) and the severity of posterior subcapsular cataract ($r = 0.3$, $P = .01$). The Modulation Transfer Function was correlated with visual acuity ($r = -0.5$, $P = .0001$). No correlations were found with visual symptoms.

The correlations between Objective Scatter Index and visual acuity in each cataract group are displayed graphically in Figure 4. In the groups with low and moderate levels of visual symptoms, the Objective Scatter Index values were correlated with visual acuity ($r = 0.5$, $P = .0006$) and with the severity of posterior subcapsular cataract ($r = 0.6$, $P = .0001$). Visual acuity was correlated with the severity of nuclear cataract ($r = 0.4$, $P = .02$) and cortical cataract ($r = 0.4$, $P = .03$). In the group with high level of visual symptoms, no correlations were found.

In eyes with a visual acuity worse than 20/40 and a low (n = 5), moderate (n = 17), or high level of visual symptoms (n = 27), we found correlations between the Objective Scatter Index values and the severity of posterior subcapsular cataract ($r = 0.6$, $P = .002$). The Objective Scatter Index values also were correlated with the frequency ($r = -0.4$, $P = .01$), severity ($r = -0.5$, $P = .01$), and bothersome quality ($r = -0.5$, $P = .009$) of visual symptoms.

In eyes with a visual acuity of 20/32 or better and a low (n = 30), moderate (n = 27), or high level (n = 1) of visual symptoms visual acuity was correlated to the severity of nuclear and cortical cataract ($r = 0.5$ and $P = .003$, and $r = 0.3$ and $P = .003$, respectively). The Modulation Transfer Function cutoff values were correlated with the severity of nuclear cataract ($r = 0.3$, $P = .02$) and the frequency, severity, and bothersome quality of the visual symptoms ($r = 0.3$ and $P = .05$, $r = 0.3$ and $P = .04$, and $r = 0.3$ and $P = .03$, respectively). The Objective Scatter Index value was correlated with the severity of posterior subcapsular cataract ($r = 0.4$, $P = .0006$).

DISCUSSION

IN THIS STUDY, A NEW OBJECTIVE APPROACH TO ASSESS cataracts based on double-pass measurements was examined. The method uses a parameter called the Objective Scatter Index, extracted from the retinal image of a point light source that quantifies the intraocular light scattering. Because it is based on double-pass measurements, neither the active participation of the patient (as with BCVA measurement), nor the ophthalmologist's expertise (as with Lens Opacities Classification System III grading) are needed. The Optical Quality Analysis System parameters already have been used to assess light scattering in patients with uveitis. Anterior chamber cells were correlated with the Objective Scatter Index ($r = 0.9$, $P = .007$) in a study by Nanavaty and associates.[7] The Optical Quality Analysis System parameters also have been used to evaluate the

TABLE. Characteristics of Visual Acuity, Cataract, and Visual Symptoms Groups in Objective and Subjective Assessments of Ocular Light Scattering

	Visual Acuity		Cataract			Visual Symptoms		
	≤ 20/40 (n = 77)	≥ 20/32 (n = 128)	Nuclear (n = 106)	Cortical (n = 40)	PSC (n = 53)	Low (n = 44)	Moderate (n = 48)	High (n = 15)
Age (y)	69.4 ± 11.7	67.4 ± 10.6	71.4 ± 8.9	71.2 ± 8.2	61.9 ± 12.6	71.3 ± 12.2	69 ± 11.8	65.9 ± 7
Visual acuity (logMAR)	0.4 ± 0.2	0.07 ± 0.1	0.2 ± 0.3	0.2 ± 0.2	0.3 ± 0.3	0.1 ± 0.2	0.2 ± 0.2	0.3 ± 0.1
OSI	6.9 ± 3.6	2.8 ± 2.6	3.9 ± 3.3	3.4 ± 2.6	5.3 ± 3.8	3.6 ± 3.1	3.8 ± 3.5	3.5 ± 2.5
MTF (cpd)	8.4 ± 5.8	19.5 ± 10.8	16 ± 10	16 ± 12	14.6 ± 10.3	16 ± 9.3	17 ± 11	15.0 ± 7.1
Frequency	48.6 ± 20.1	36.4 ± 15.1	38.5 ± 19.7	46.5 ± 18.6	40.6 ± 16.8	26.9 ± 8	45.5 ± 9.6	73.3 ± 8.6
Severity	45.4 ± 20.1	30.2 ± 13.9	33.1 ± 28.4	41.1 ± 21.5	35.1 ± 15.1	21.6 ± 5.5	39.8 ± 9.1	68.1 ± 9.4
Discomfort	50 ± 23.2	31.8 ± 15.5	35.9 ± 20.6	44.4 ± 25.3	40.1 ± 17.7	22.9 ± 5.9	43.3 ± 10	77.1 ± 9.7

cpd = cycles per degree; logMAR = logarithm of the minimal angle of resolution; OSI = objective scatter index; MTF = modulation transfer function; PSC = posterior subcapsular cataract.

in vitro optical quality of monofocal IOLs by Vilaseca and associates.[8]

The results of this study show that Objective Scatter Index is correlated significantly with the severity of the cataract and with visual acuity in all cataract groups. The Modulation Transfer Function cutoff values also were correlated significantly with the severity of cataract and visual acuity in all cataract groups. These results mean the Objective Scatter Index and Modulation Transfer Function could be useful parameters to discriminate objectively clear crystalline lens from cataract. Ortiz and associates found a significant negative correlation between the Modulation Transfer Function cutoff values and lens density as evaluated by a Scheimpflug camera ($r = -0.4$, $P = .006$) in early and moderate nuclear cataract in a sample of 34 eyes.[9] In this study, the same negative correlation was found in a larger eyes sample ($r = -0.5$, $P < .0001$) between the Modulation Transfer Function cutoff and the severity of nuclear cataract according to the Lens Opacity Classification System III grading system. The Objective Scatter Index also was found to correlate with the severity of nuclear cataract and with the severity of posterior subcapsular cataract. Artal and associates found that an Objective Scatter Index lower than 1 characterizes a noncataract eye, whereas a value of approximately 2 corresponds with an early cataract and a value of more than 2 corresponds with a moderate to mature cataract eye.[10] In our study, the Table shows that the Objective Scatter Index value is higher than 2 in each group, even in the group with a visual acuity of 20/32 or better (mean Objective Scatter Index, 2.8 ± 2.6). This result confirms that ocular light scattering in patients with cataract and good visual acuity is significant and helps to explain the potential impact on quality of vision. Vision is affected by cataracts in several subjective ways such as glare, haloes, and starbursts. Therefore, cataracts impair vision in many more ways than visual acuity testing alone indicates. The nature of the effect varies with the degree of the cataract and with the morphologic features of the cataract.[11,12]

One of the many clinical classifications that have been used to evaluate the grade of cataract is the Lens Opacities Classification System III.[5] It is the most commonly used classification that grades cataracts by comparing slit-lamp images with a photographic image. In this study, correlations were found between Objective Scatter Index and nuclear, cortical, and posterior subcapsular cataract grades as displayed in Figures 1, 2, and 3. Nevertheless, the Lens Opacities Classification System III is an examiner subjective system of cataract evaluation that does not provide direct information on the consequences of the lens opacification on the retinal image quality. The assessment of a patient's visual disability therefore is not a simple task and cannot be based solely on visual acuity testing or on the measurement of the amount of cataract by the Lens Opacities Classification System III.[13] Wavefront evaluation techniques have been used to measure optical aberrations in the human eye.[14] Many studies have concluded that Hartmann-Shack aberrometers may overestimate image quality in eyes affected by scattering (e.g., cataract or multifocal IOL).[15–19]

The use of questionnaires can provide an effective way of determining the views of the patient. Modern questionnaires developed and scored with Rasch analysis provide a quantitative linear measure of a specific latent trait, for example, quality of life or quality of vision.[20] The use of patient-reported outcomes is effective in assessing the effect of cataract on a patients' everyday lives, such as the Quality of Vision questionnaire.[21] In this study, no statistically significant correlations were found in eyes with a high level of visual symptoms, but this group included only 15 eyes. In eyes with low and moderate levels of visual symptoms, correlations were found between Objective Scatter Index and posterior subcapsular cataract. This questionnaire can be beneficial in the decision-making process, particularly in patients with minimal visual acuity loss yet symptomatic cataract. Furthermore, as far back as 1981, Bernth-Petersen used a questionnaire in an attempt

to quantify the perceived visual disability of cataract patients.[22] Of 123 patients, he found 25 with relatively good VA, but with a high visual disability score, and suggested that these patients should have their cataracts extracted at an earlier stage. Hence, visual acuity can be crude and does not always provide the full picture of functional vision, especially in patients with cataract. This is one of the reasons why we collected the data from visual acuity testing, Lens Opacities Classification System III grading, Optical Quality Analysis System measurements, and patient-reported outcomes from the Quality of Vision questionnaire.

The guidelines of the Agency for Health Care Policy and Research[23] suggested the following indications for cataract surgery in 1993: (1) the patient's ability to function in their desired lifestyle is reduced because of poor vision; (2) visual acuity is 20/50 or worse and the reduction is solely the result of cataract; (3) the patient decides that the expected improvement in function outweighs the potential risk, cost, and inconvenience of surgery after being given appropriate information[24]; and (4) if the Snellen acuity is better than 20/40, the patient should report visual disability resulting from glare or dim illumination, from monocular diplopia or polyopia, or from a visual disparity between the 2 eyes.

There is a need for modified guidelines for cataract surgery. Several studies report the functional benefits of early cataract surgery in patients with 20/20 preoperative visual acuity.[25–28] The decision to recommend cataract surgery should be based on factors such as visual acuity, visual impairment, subjective quality of vision, and potential for functional benefits. The repeatability and the reliability of the Optical Quality Analysis System measurements have been studied by Saad and associates, who found that the repeatability limit was good for the Objective Scatter Index, Modulation Transfer Function, and Strehl ratio and that the reliability of this device complies with the requirements for quantitative assessment of ocular scattering.[29] Hence, Optical Quality Analysis System measurements, Quality of Vision questionnaire scores, Lens Opacities Classification System III grading, and visual acuity, which collectively provide a variety of objective and subjective measurements, could be a part of the cataract surgery guidelines.

REFERENCES

1. Artal P, Ferro M, Miranda I, Navarro R. Effects of aging in retinal image quality. *J Opt Soc Am A* 1993;10(7):1656–1662.

2. Guirao A, Gonźlez C, Redondo M, Geraghty E, Norrby S, Artal P. Average optical performance of the human eye as a function of age in a normal population. *Invest Ophthalmol Vis Sci* 1999;40(1):203–213.

3. Pujol J, Gispets J, Arjona M. Optical performance in eyes wearing two multifocal contact lens designs. *Ophthalmic Physiol Opt* 2003;23(4):347–360.

4. Guirao A, Redondo M, Geraghty E, Piers P, Norrby S, Artal P. Corneal optical aberrations and retinal image quality in patients in whom monofocal intraocular lenses were implanted. *Arch Ophthalmol* 2002;120(9):1143–1151.

5. Chylack LT Jr, Wolfe JK, Singer DM, et al. The Lens Opacities Classification System III. The Longitudinal Study of Cataract Study Group. *Arch Ophthalmol* 1993;111(6):831–836.

6. McAlinden C, Pesudovs K, Moore JE. The development of an instrument to measure quality of vision: the Quality of Vision (QoV) questionnaire. *Invest Ophthalmol Vis Sci* 2010;51(11):5537–5545.

7. Nanavaty MA, Stanford MR, Sharma R, Dhital A, Spalton DJ, Marshall J. Use of the double-pass technique to quantify ocular scatter in patients with uveitis: a pilot study. *Ophthalmologica* 2011;225(1):61–66.

8. Vilaseca M, Arjonat M, Pujol J, Issolio L, Guell JL. Optical quality of foldable monofocal intraocular lenses before and after injection: comparative evaluation using a double-pass system. *J Cataract Refract Surg* 2009;35(8):1415–1423.

9. Ortiz D, Alio J, Ruiz-Colecha J, Oser U. Grading nuclear cataract opacity by densitometry and objective optical analysis. *J Cataract Refract Surg* 2008;34(8):1345–1352.

10. Artal P, Benito A, Pérez GM, et al. An objective scatter index based on double-pass retinal image of a point source to classify cataracts. *PLoS One* 2011;6(2):e16823.

11. Chua BE, Mitchell P, Cumming RG. Effects of cataract type and location on visual function: the Blue Mountains Eye Study. *Eye (Lond)* 2004;18(8):765–772.

12. Stifter E, Sacu S, Weghaupt H. Functional vision with cataracts of different morphologies: comparative study. *J Cataract Refract Surg* 2004;30(9):1883–1891.

13. Phelps Brown NA. The morphology of cataract and visual performance. *Eye* 1993;7(1):63–67.

14. McAlinden C, McCartney M, Moore J. Mathematics of Zernike polynomials: a review. *Clin Experiment Ophthalmol* 2011;39(8):820–827.

15. Díaz-Doutón F, Benito A, Pujol J, Arjona M, Güell JL, Artal P. Comparison of the retinal image quality with

a Hartmann-Shack wavefront sensor and a double-pass instrument. *Invest Ophthalmol Vis Sci* 2006;47(4):1710–1716.

16. Gatinel D. Limited accuracy of Hartmann-Shack wavefront sensoring in eyes with diffractive multifocal IOLs. *J Cataract Refract Surg* 2008;34(11):1817–1818.

17. Charman WN, Montés-Micó R, Radhakrishnan H. Problems in the measurement of wavefront aberration for eyes implanted with diffractive bifocal and multifocal intraocular lenses. *J Refract Surg* 2008;24(3):280–286.

18. Charman WN, Montés-Micó R, Radhakrishnan H. Can we measure wave aberration in patients with diffractive IOLs? *J Cataract Refract Surg* 2007;33(11):1997.

19. Campbell CE. Wavefront measurements of diffractive and refractive multifocal intraocular lenses in an artificial eye. *J Refract Surg* 2008;24(3):308–311.

20. McAlinden C, Skiadaresi E, Pesudovs K, Moore JE. Quality of vision after myopic and hyperopic laser-assisted subepithelial keratectomy. *J Cataract Refract Surg* 2011;37(6):1097–1100.

21. McAlinden C, Gothwal VK, Khadka J, Wright TA, Lamoureux EL, Pesudovs K. A head-to-head comparison of 16 cataract surgery outcome questionnaires. *Ophthalmology* 2011;118(12):2374–2381.

22. Bernth-Petersen P. Visual functioning in cataract patients. Methods of measuring and results. *Acta Ophthalmol* 1981; 59(2):198–205.

23. O'Day DM. Management of cataract in adults. Quick reference guide for clinicians. The Cataract Management Guideline Panel of the Agency for Health Care Policy and Research. *Arch Ophthalmol* 1993;111(4):453–459.

24. Elliott DB. Evaluating visual function in cataract. *Optom Vis Sci* 1993;70(11):896–902.

25. Amesbury EC, Grossberg AL, Hong DM, Miller KM. Functional visual outcomes of cataract surgery in patients with 20/20 or better preoperative visual acuity. *J Cataract Refract Surg* 2009;35(9):1505–1508.

26. Adamsons IA, Vitale S, Stark WJ, Rubin GS. The association of postoperative subjective visual function with acuity, glare, and contrast sensitivity in patients with early cataract. *Arch Ophthalmol* 1996;114(5):529–536.

27. Superstein R, Boyaner D, Overbury O. Functional complaints, visual acuity, spatial contrast sensitivity, and glare disability in preoperative and postoperative cataract patients. *J Cataract Refract Surg* 1999;25(4):575–581.

28. Charalampidou S, Loughman J, Nolan J, et al. Prognostic indicators and outcome measures for surgical removal of symptomatic nonadvanced cataract. *Arch Ophthalmol* 2011; 129(9):1155–1161.

29. Saad A, Saab M, Gatinel D. Repeatability of measurements with a double-pass system. *J Cataract Refract Surg* 2010; 36(1):28–33.

Biosketch

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Biosketch

Damien Gatinel, MD, is the chief of the Department of Anterior Segment and Refractive Surgery at the Rothschild Foundation, Paris, France. His research focuses on the optical quality of the human eye, intraocular lens design, laser photoablation profiles and detection of the early manifestations of subclinical keratoconus. Dr Gatinel is a board member of the Research Committee of the European Society of Cataract and Refractive Surgery and a member of the American Academy of Ophthalmology.