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MASTER THESIS WORK

OBJECTIVE INTRAOCULAR SCATTERING EVALUATION IN CATARACT PATIENTS

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Objective intraocular scattering evaluation in cataract patients.

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Abstract. Everyday ophthalmologists visit several patients with cataracts, which must be analyzed and properly classified. Procedures commonly used nowadays for this purpose are the visual acuity assessment and the cataract gradation by means of direct observation of the crystalline lens through a slit lamp. These methods are subjective since the first requires the active participation of the patient and the gradation achieved by the second one totally depends on the physician and his o her expertise. In this study, a new objective approach to assess cataracts based on double-pass measurements is presented. The method uses a new parameter called Optical Scatter Index (OSI), extracted from the retinal image, which accounts for the intraocular scattering present in the eye. In this study we analyzed 59 patients: 20 of them without cataracts (control group) and 39 with cataracts of different degree and type. The values obtained with the new technique are compared with those achieved with the more conventional subjective procedures. The results of the study show that OSI is a powerful tool to evaluate cataracts with a good criterion.

Keywords: crystalline, cataract, scatter, optical quality, double-pass

1. Introduction

Different structures form the human eye such as the cornea, the iris, the crystalline lens and the retina. The cornea and the crystalline lenses are the most important optical surfaces of the human eye, and they have an important role for its right operation. Both should have a good optical quality in order to provide the best possible retinal image, and furthermore, the crystalline lens or lens might allow the focus of objects at different distances.

The crystalline lens is a transparent and biconvex lens located at the posterior chamber of the eye. Its transparency is given by the absence of blood vessels, the specific distribution of fibers and the perfect equilibrium of ions and proteins. With time, this balance works off and a cataract can appear. The lens starts becoming opaque, increasing the amount of scattered light in the eye and thus reducing the visual acuity of the patient. On the other hand, the contrast sensitivity decreases and, depending on the type of cataract (anterior or posterior subcapsular, nuclear etc.), the patient's refractive error can also be intensified.

Nowadays, cataracts are the main cause of blindness in the world and four out of ten people over 60 years old develop them. For this reason, when a cataract appears it must be extracted. Currently the physician is who decides when to perform the cataract surgery, depending on the observed cataract degree. There are several subjective procedures commonly employed by the ophthalmologists to evaluate cataracts such as visual acuity tests and slit-lamp examination.

The slit-lamp examination consists of the direct observation of the lens by means of the slit-lamp from which a first gradation of the state of every cataractous eye is assessed (from 0 to 4). This classification is known as LOCS III[1]. However, it has been recently observed that intraocular scattering, which is directly related to the cataract degree, can be objectively measured using the double-pass technique[2,3]. Such a technique is a standard procedure commonly used to obtain the eye's optical quality, as an alternative to conventional wavefront aberrometers[4], usually based on the Hartmann-Shack sensor, used in the clinical practice to assess the eye's aberrations.

The double-pass technique consists of the formation of a point-source image on the retina and its recording after the double pass of the light through the ocular media by means of a CCD camera. This method is able to capture all the optical information of the eye, although it is difficult to isolate the exact contribution of the factors involved in the degradation of the retinal image, which basically are the high-order aberrations and intraocular scattering (diffraction has a small contribution with the standard values of pupil diameter). On the other hand, wavefront aberrometers may overestimate the retinal image quality in eyes where intraocular scattering is prominent, since they only take into account ocular aberrations[5]. For this reason, the use of the double-pass technique in cataract patients has revealed as a very important and useful method to quantify intraocular scatter.

The double-pass technique has been successfully used in different studies to assess the eye's optical quality. It has been used to quantify the optical aberrations in eyes implanted with intraocular lenses[6,7], to analyze the changes of the aberrations of the human eye as a function of age[8], and to compare retinal image quality between IOL implantation and LASIK for myopic correction[9]. Furthermore, there have been few attempts to use a double-pass system in order to evaluate the scattering of the eye produced by a cataract[10] although only preliminary results have been obtained.

For this reason, the purpose of this study is to complete the analysis of the intraocular scattered light in a great amount of cataractous patients by means of a double-pass system and to establish a quantitative comparison between this objective evaluation and the results obtained with more conventional subjective procedures such as the visual acuity tests and the LOCS III gradation.

2. Double-pass System (OQAS™)

In this study, we used the clinical double-pass based instrument Optical Quality Analysis System OQAS (Visiometrics S.L., Terrassa, Barcelona) developed by the Centre for Sensors, Instruments and Systems Development (CD6) of the Technical University of Catalunya (UPC) in collaboration with the Laboratorio de Óptica de la Universidad de Murcia (LOUM). This instrument consists of an optical head and laser equipment, a computer workstation and a custom designed software. It allows measuring the joint effect of high-order optical aberrations and scattered light, thus providing complete information of the optical quality of the patient's eye.

As it was mentioned above, the optical design of the OQAS is based on the double-pass technique. The principal parts of it are explained in detail below (Figure 1):

Firstly, a point source image is formed on the patient's retina using a diode laser with a 780nm wavelength coupled to a spatial filter. The light coming from the laser is collimated with the lens L1 and then the beam passes through an aperture diaphragm with a fixed diameter of 2mm, which acts as the entrance pupil (EP) of the system and is located at the conjugate plane of the patient's pupil. After that, the light passes through the beam splitters BS1 and BS2. The laser beam is reflected on the mirrors M1 and M4 and passes through a compensator of the patient's ametropia based in a Badal's system, which consists of lenses L3, L4 and mirrors M2 and M3. The distance between the lenses is variable, so, the optical path can be changed, thus compensating the spherical refraction of the patient. At the end of this first step, the laser beam is reflected with a dichroic filter DF, and the ocular optics is responsible of focusing the light beam on the retina.

Secondly, around 3% of the light that reaches the retina is reflected and after crossing the ocular media, it passes through the dichroic filter DF, the Badal system and the mirror M1 until beam splitter BS2. Then, the beam crosses another aperture diaphragm (ExP), which is the exit pupil of the system (conjugate of the eye's papillary plane). The EP has a changeable diameter and is the effective exit pupil if its diameter is smaller than the eye's natural pupil. At the end of the second step, the objective lens L5 focuses the retinal image on the detector of the camera CCD1.

The instrument also incorporates a system with which the pupil plane can be seen on-line. The patient's eye is illuminated with several infrared LED's (IL), which do not affect the pupil's size of the patient. In this case, the reflected light coming from the eye is transmitted by the dichroic filter (DF) and is reflected on the mirror (M4) until the image is captured by the camera CCD2, which is focused on the conjugate plane of the EP (entrance pupil) and ExP (exit pupil) of the system. A fixation test illuminated with white light has been introduced in the system to minimize the ocular movements and the accommodation fluctuations during the measurement. The light from the test passes through the collimator lens L2, crosses the beam splitters BS1 and BS2, is reflected by mirrors M1 and M4, crosses the Badal's system and the dichroic filter DF and, finally, arrives at the patient's retina.
Finally, it must be mentioned that in order to align the eye with the instrument, all the optical system is set on a head that allows a horizontal movement. It must also be remarked that the double-pass measurements are performed with the patient's refractive error corrected; spherical refractive error is automatically corrected by the double-pass system, and astigmatism is corrected with an external lens, since the instrument is not be able to correct cylindrical errors. The outcome of the OQAS strongly depends on the uncorrected refractive error as this factor directly affects the optical quality of the retinal image. Therefore, it is very important to correct the refractive error completely while performing measurements with this instrument.

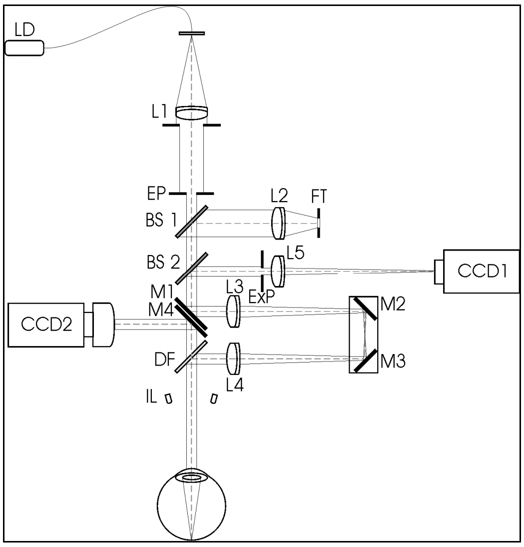

Figure 1. Complete OQAS Optical Design.

The dimensions and the space distribution of the energy along the double-pass image are related to the eye's optical quality. The center part of this image is mainly affected by ocular aberrations: the larger the spot size is, the worse the retinal image quality is. However, external parts of the double-pass image mostly contain information of the scattered light, caused by the loss of transparency of one or more of the ocular optical structures, such as haze (a mutation of the subepitelial tissue of the cornea[11], corneal opacities, cataracts, etc. Specifically, the OQAS system allows the objective evaluation of the amount of intraocular scattering by means of a self-called Objective Scatter Index (OSI)[12,13] obtained from the digital levels of the double-pass images at certain excentricities and used in this study to quantify the diffused light present in the cataractous eyes analyzed. Values of this parameter lower than 2 are often related to eyes with low scattering, values from 2 to 5 correspond to eyes with moderate diffused light such as incipient cataracts, meanwhile values higher than 5 are normally linked to eyes with very high scattered light, such as eyes with mature cataracts.
Furthermore, from the double-pass image, OQAS computes the Modulation Transfer Function (MTF), which represents the loss of contrast produced by the eye's optics as a function of the spatial frequency. The system also provides other parameters related to the MTF function that account for the eye's optical quality: the OQAS values (OVs) at contrasts of 100%, 20% and 9%[14], and the Strehl ratio[15]. The OVs correspond to three specific frequencies of the MTF that

describe the eye's optical quality for the contrast values mentioned. Specifically, OV 100% is directly related to the MTF cut-off frequency and therefore to the patient's visual acuity, although it has a different normalization factor. In general, OVs higher than 1 are associated to very high retinal image quality. On the other hand, the Strehl ratio is computed as the ratio between the areas under the MTF curve of the measured eye and that of the aberration-free eye, and therefore it provides more global information on the optical quality. However OVs can be used to obtain more specific information (which may otherwise remain hidden) on the behavior of the eye at different contrasts, which can be very useful from the clinical point of view.
The standard software program, provided with the OQAS system, automatically selects the energy of the laser used with a fixed exposure time of the camera (240ms) in order to obtain an acceptable retinal image of the patient. The software's routine changes the electrical voltage of the laser used from 0 to 3.5 V which allow obtaining radiant powers from 0 to 1mW on the retina approximately. This amount of energy is enough for normal eyes, but not in eyes with mature cataracts, since the amount of reflected light is very small because of the low transparency of the crystalline lens. Furthermore, this action can notably increase the time of the measurement since the routine starts from low powers and keeps increasing them until an acceptable double-pass image is shown on the screen. For these reasons, custom made software has been developed to be used in this study. This software incorporates the option of manually modifying the energy of the laser to obtain the best retinal images. The advantage of this program is that the light reaching the retina can be increased by changing the laser voltage, but on the other hand, the exposure time of the CCD camera can also be increased, which allows to obtain good double-pass images even the eye has a mature cataract.

3. Patients and methods

This study included the analysis of 20 young patients (40 eyes) as control group and 39 patients (56 eyes) with different type and degree of cataracts.
Patients' examination was performed at the Hospital Universitari Mútua de Terrassa under supervision of Dr. A. Salvador and Dr. M. J. Romero and at the Centre UniversitarI de la Visió (CUV) in Terrassa, under the supervision of optometrist J. C. Ondategui.

Patients were analyzed with the following protocol:

- Patient's anamnesis (medical history)
- Determination of the subjective manifest refraction
- Measurement of the best-spectacle corrected visual acuity (BSCVA) and uncorrected visual acuity (UCVA).
- Measurement of the Contrast Sensitivity Function (CSF).
- Determination of the OSI parameter by means of the OQAS system with a 4mm pupil with the standard software.

In order to assess visual acuity a standard logMAR visual acuity test at 4 meters was used. LogMAR (Logarithm of the Minimum Angle of Resolution) consists of a back-illuminated test with a chart which has been designed using high contrast lettering, and that allows the analysis of visual acuity scores more effectively and precisely than standard visual acuity tests.
CSF function informs us about the patients' capability to see different spatial frequencies at different contrasts. In this study, patient's CSF was analyzed with the CVS-1000E test at 3m, which is the test most used worldwide. It consists of four rows with tests of different spatial frequency (3, 6, 12 and 18 cicles/degree) and contrasts[16]. The human contrast sensitivity function shows a typical band-pass shape peaking at around 4 cycles per degree with sensitivity dropping off either side of the peak. This tells us that the human visual system is able to detect gratings of 4 cycles per degree at a lower contrast than at any other spatial frequency. CSF is related to the MTF, although MTF does not take into account the neurological process that occurs after retinal image formation.

The inclusion criterion in the control group was restricted to patients with BSCVA equal or lower than 0.2 (in LogMAR units) and normal values of contrast sensitivity, in order to avoid patients with problems of transparency of the ocular media as a reference.

Furthermore, the protocol followed in the case of the cataract patients also included the cataract degree assessed using slit-lamp examinations performed by the physician, according to a gradation derived from the LOCS III classification system[17]. This subjective gradation of cataracts is based on the direct observation of the cataract with a biomicroscope. Figure 2 shows, the different degrees of cataracts commonly considered (from 0 to 4). Specifically, three different groups of cataract patients were considered in this study regarding the LOCS classification: patients with Gradation 1 (Grad. 1) – early cataracts, Gradation 2 (Grad. 2) – moderate cataracts, and Gradation 3 (Grad. 3) – mature cataracts. Often, cataract surgery takes place between gradations 2 and 3, although this decision made by the ophthalmologist also concerns the BSCVA of the patient, and for this reason patients with a gradation of 4 are not available.

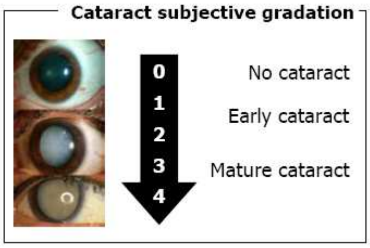

Figure2. Cataract Subjective Gradation.

Cataracts are also classified regarding its position in the crystalline lens. In this study two different kinds of cataracts have been analyzed: 49 eyes with cortical nuclear cataracts (CN) and 7 posterior subcapsular cataracts (SCP). CN cataracts are the most commonly seen in patients who have diabetes. Cortical nuclear cataracts are located at the central core of the lens although they can also be at the outer rims of the lens. Its exact localization differs from patient to patient and depending on the affected zone, the visual acuity can vary in more or less severity. On the other hand, SCP cataracts progress more rapidly. These affect the back of the lens, causing glare and blurriness. This type of cataract strongly affects the visual acuity since it generally appears around the pupil of the patient.

Finally, optical quality was assessed by means of the OQAS system using the standard software provided with the equipment in the case of patients belonging to the control group. The patient's refractive error was corrected during these measurements: the spherical refractive error was automatically corrected by the double-pass system while the astigmatism was corrected with an external cylindrical lens, in order to achieve the best possible optical quality. The determination of the OSI in the case of cataract patients was performed with the custom made OQAS software.

Table 1 shows the patients demographics and manifest subjective refraction (sphere, cylinder and spherical equivalent) for patients belonging to the control group and to the three cataract groups classified using LOCS III. For each of these parameters the mean, standard deviation and corresponding range are detailed.

	Mean ± standard deviation (range)			
	Control group	**Cataract group**		
	Grad. 0	**Grad. 1**	**Grad. 2**	**Grad. 3**
Age (years)	21.70 ± 1.84 (19 to 26)	69.14 ± 8.24 (55 to 80)	71.16 ± 7.56 (55 to 82)	70.50 ± 10.02 (55 to 82)

Gender	**Male**	25%	50%	28%	27.27%
	Female	75%	50%	72%	72.72%
Sphere (D)		0.00 ± 0.00 (0.00 to 0.00)	0.84 ± 2.69 (-6.50 to +3.00)	1.33 ± 1.56 (-1.75 to 4.25)	-0.25 ± 3.47(-6.25 to +4.75)
Cylinder (D)		0.00 ± 0.00 (0.00 to 0.00)	-1.09 ± 0.65 (-2.50 to 0.00)	-1.09 ± 0.71 (-2.75 to 0.00)	-2.16 ± 1.57 (-6.00 to 0.00)
SE (D)		0.00 ± 0.00 (0.00 to 0.00)	0.29 ± 2.65 (-7.00 to +2.63)	0.79 ± 1.61 (-2.38 to +3.63)	-1.31 ± 3.51 (-7.00 to +3.75)

Table 1. Patient demographics and manifest refractive error of patients belonging to the control group, and the three groups of graded cataract patients. (SE: Spherical equivalent).

5. Results

Figure 3 shows double-pass images obtained with OQAS associated to some representative patients belonging to the control group and to the three groups of cataract patients.

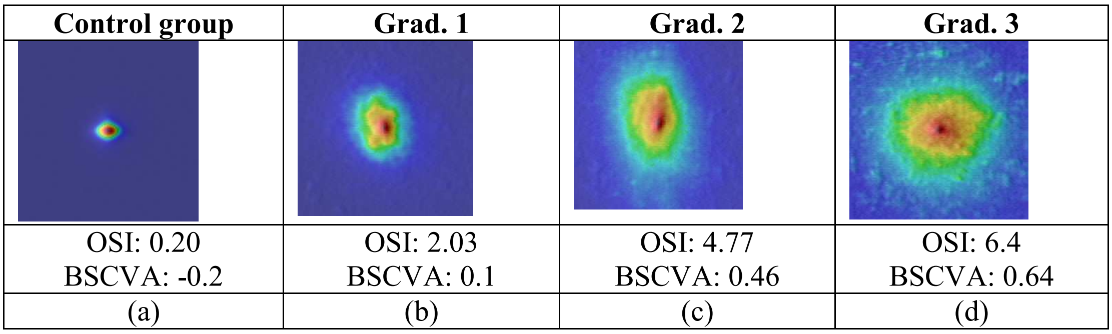

Figure 3. Double-pass images corresponding to some representative patients. (a) Patient without cataract, (b) patient with cataract of gradation 1, (c) patient with cataract of gradation 2, (d) patient with cataract of gradation 3. The OSI (Objective Scatter Index) and the best spectacle-corrected visual acuity (BSCVA) corresponding to each patient are also shown.

As it can be observed in the figure, the presence of a cataract worsens in general the double-pass image and, thus, the optical quality of the eye. It is important to stand out that the cataract does not only affect the central part of the double-pass image, which is mainly related with the aberrations of the eye, but it has a great impact on the diffused light, caused by the lack of transparency of the crystalline lens. When the gradation of the cataract increases, the scattered light also increases, which can be observed in the outer parts of the images where a higher degree of energy can be found.

Visual acuity with (BSCVA) and without (UCVA) correction are shown in Table 2 for all considered groups of patients. Furthermore, in this table the OSI parameter measured with OQAS is also reported.

	Mean ± standard deviation (range)			
	Control group	**Cataract group**		
	Grad. 0	**Grad. 1**	**Grad. 2**	**Grad. 3**
Nº of eyes	40	14	25	11
UCVA	-0.10 ± 0.10 (-0.30 to 0.06)	0.35 ± 0.50 (0.04 to 2.00)	0.52 ± 0.41 (0.04 to 2.00)	1.19 ± 0.81 (0.14 to 2.00)
BSCVA	-0.10 ± 0.10 (-0.30 to 0.06)	0.10 ± 0.10 (0.02 to 0.40)	0.24 ± 0.17 (0.00 to 0.64)	0.78 ± 0.67 (0.06 to 2.00)
OSI	0.31 ± 0.14 (0.05 to 0.74)	3.28 ± 3.29 (1.13 to 12.37)	4.02 ± 2.64 (0.47 to 11.54)	5.79 ± 2.85 (2.43 to 12.51)

Table 2: Number of eyes, UCVA, BSCVA and OSI of patients belonging to the control group, and the three groups of graded cataract patients.

It can be seen that the average of OSI is different for each represented group. OSI is clearly higher if the development of the cataract is more advanced. In the control group, OSI never overpasses value 1, while the average of this parameter increases when the gradation of cataract given by ophthalmologist increases. The decrease of the retinal image quality is translated in a deterioration of the visual acuity of the patients (UCVA and BSCVA), obtaining higher (worse) values of these parameters for patients with more mature cataracts (in logMAR units).

To determine the statistical significance of the obtained results among groups, a statistical analysis by paired sample *t* test of BSCVA and OSI data was performed. A P value lower than 0.05, was considered statistically significant. Tables 3 and 4 report the main results obtained in the statistical analysis, when the BSCVA and the OSI parameter are compared.

BSCVA	**Control Group**	**Grad. 1**	**Grad. 2**	**Grad. 3**
Control Group	-	<0.01	<0.01	**<0.01**
Grad. 1	-	-	<0.01	**<0.01**
Grad. 2	**-**	**-**	**-**	**<0.01**
Grad. 3	**-**	**-**	**-**	**-**

Table 3: P value of the statistical analysis of BSCVA among the different groups.

OSI	**Control Group**	**Grad. 1**	**Grad. 2**	**Grad. 3**
Control Group	**-**	**<0.01**	**<0.01**	**<0.01**
Grad. 1	**-**	**-**	**0.43**	**0.05**
Grad. 2	**-**	**-**	**-**	**0.07**
Grad. 3	**-**	**-**	**-**	**-**

Table 4: P value of the statistical analysis of OSI among the different groups of patients.

It can be seen that statistically significant differences in terms of BSCVA exists among all the considered groups. This means that the groups of patients can be clearly differentiated using this parameter. On the other hand, the statistical analysis performed with OSI shows that statistically significant differences also exist between the control group and the rest of the eyes with cataracts. However, no statistically significant differences can be observed among groups of eyes with cataracts, although some of them are in the limit of the statistical significance (groups with gradation 1 and 3).
The following figures (Figures 4 and 5) illustrate the correlations between BSCVA and OSI, and cataract gradation and OSI, respectively, considering all analyzed eyes and all cataract types (CN and SCP). In the left figures all the eyes are shown meanwhile right graphics illustrate the eyes separated in groups (control and cataract groups).

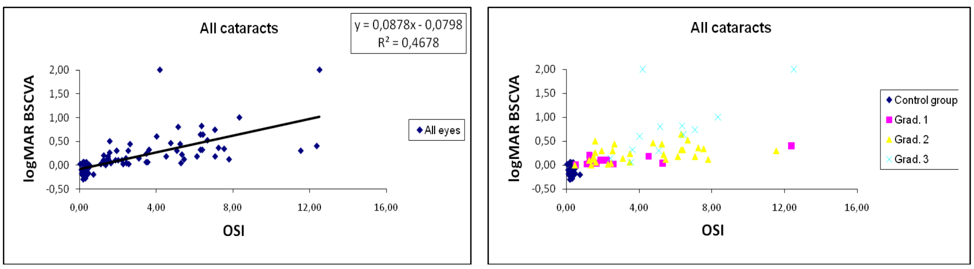

Figure 4: Correlation between BSCVA and OSI taking into account all analyzed eyes and types of cataracts (CN and SCP) (Left). The eyes are also classified by groups using different colors (Right).

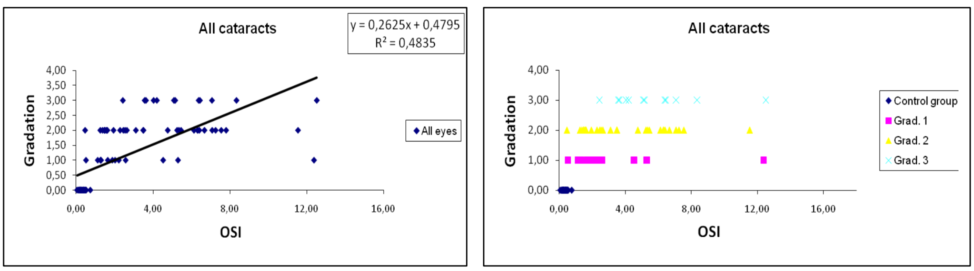

Figure 5: Correlation between cataract gradation and OSI taking into account all analyzed eyes and types of cataracts (CN and SCP) (Left). The eyes are also classified by groups using different colors (Right).

As can be seen, all the correlations found are generally rather good, if we take into account the parameters R^2 considered in the medical and ophthalmological area, where values around 0.2-0.4 are considered significant. A higher value of OSI is generally related with a higher value of visual acuity, and so, with a worse visual acuity (in logMAR scale). At the same time, it can be seen that higher values of OSI are usually related with higher gradations of cataracts made by the physicians. Furthermore, it can also be observed that meanwhile BSCVA and OSI provide a good and continuous assessment of the cataract degree of patients, LOCS III gives a too simple and discrete classification, and probably a too subjective gradation depending on the ophthalmologist, which is a clear drawback of this procedure and may be not enough to rigorously classify cataract patients in some cases.
On the other hand, it can be also noticed that there are some patients with no optimal results, especially in the case of patients of group with gradation 1 (pink), which show very high OSI values that can be indistinguishable (overlap) with results of other cataract groups (Grad.2 and Grad.3). Some of the patients belonging to groups 2 and 3 overlap, too.

Figure 6 shows the OSI values in increasing order for all analyzed eyes, codified by color depending on the group. Again, it can be seen that some patients of the group Grad.1 are mixed with patients of the other groups. Also, it can be observed that the same thing occurs with patients of groups 2 and 3, which are partially mixed between them.

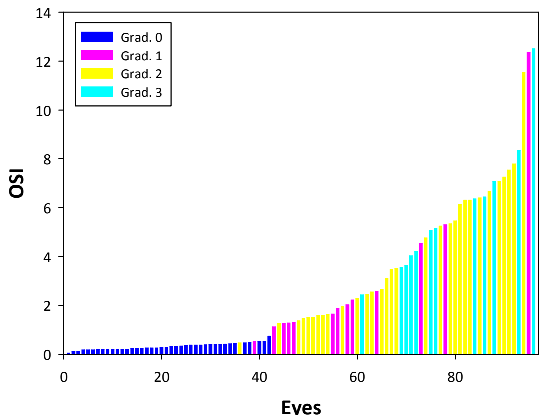

Figure 6: OSI parameter of all analyzed patients belonging to the different groups coded by color.

Figure 7 shows the BSCVA values in increasing order for all analyzed eyes, codified by color depending on the group. It can be seen that in this case, some patients of the group Grad.1 (pink) are still located among other patients of the rest of groups. However in terms of BSCVA, patients of groups Grad.2 and 3 are better discriminated than using the OSI parameter.

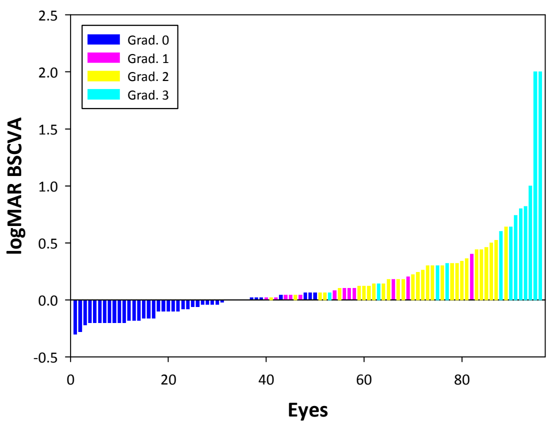

Figure 7: BSCVA of all analyzed patients belonging to the different groups coded by color.

The cause of this mismatches, both in terms of OSI and BSCVA, can be probably found in the different types of analyzed cataracts, which can have different localizations in the crystalline lens, and therefore, they can have a different influence on the patient's BSCVA (depending if they are near the pupil or not) and the OSI parameter.

For this reason, the former analysis is repeated, but separating the two different kinds of cataract (CN and SCP). In Table 5, the obtained results are shown.

	Mean ± standard deviation (range)		
Type of cataract	**Cataract group**		
Cortical Nuclear (CN)	**Grad. 1**	**Grad. 2**	**Grad. 3**
Nº of eyes	11	23	10
UCVA	0.25 ± 0.18 (0.04 to 0.60)	0.51 ± 0.42 (0.04 to 2.00)	1.11 ± 0.80 (0.14 to 2.00)
BSCVA	0.08 ± 0.06 (0.02 to 0.20)	0.25 ± 0.18 (0.00 to 0.64)	0.66 ± 0.56 (0.06 to 2.00)
OSI	2.64 ± 2.26 (1.13 to 7.80)	4.05 ± 2.66 (0.47 to 11.54)	5.95 ± 2.95 (2.43 to 12.51)
Posterior Subcapsular (SCP)			
Nº of eyes	3	3	1
UCVA	0.74 ± 1.09 (0.06 to 2.00)	0.20 ± 0.09 (0.12 to 0.30)	2.00 ± 0.00 (2.00 to 2.00)
BSCVA	0.17 ± 0.20 (0.02 to 0.40)	3.70 ± 2.97 (1.47 to 7.08)	2.00 ± 0.00 (2.00 to 2.00)
OSI	5.61 ± 5.86 (1.89 to 12.37)	2.00 ± 0.00 (2.00 to 2.00)	4.20 ± 0.00 (4.20 to 4.20)

Table 5: Number of eyes, UCVA, BSCVA and OSI of patients belonging to the three groups of graded cataract patients classified by type of cataract (CN: cortical nuclear; SCP: Posterior subcapsular).

In the following figures (Figure 8 and 9) the obtained results for CN cataracts are presented.

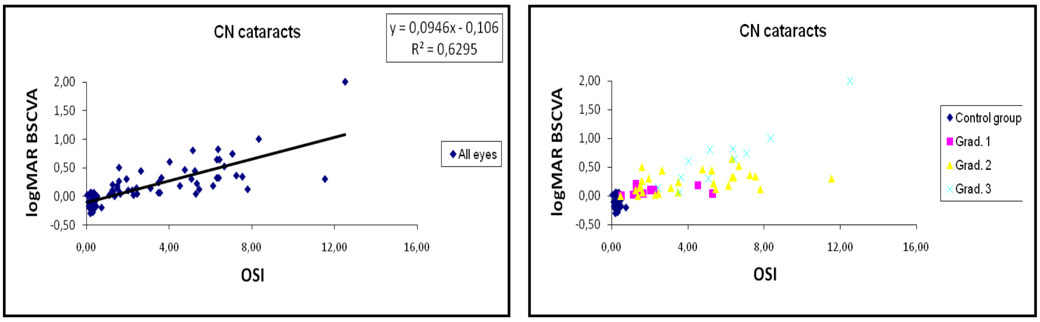

Figure 8: Correlation between BSCVA and OSI taking into account the eyes with CN cataract (Left). The eyes are also classified by groups using different colors (Right).

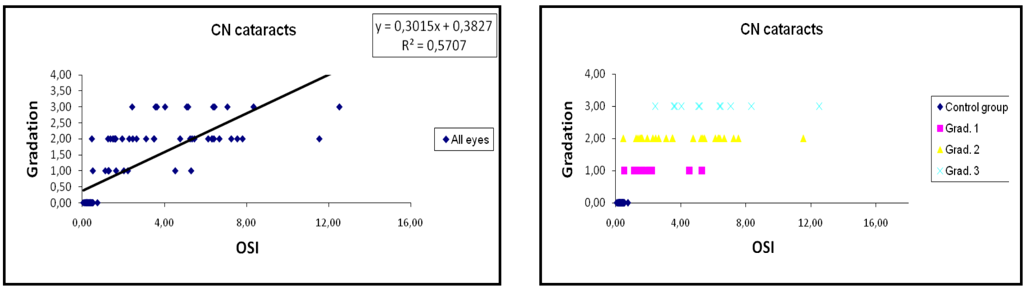

Figure 9: Correlation between cataract gradation and OSI taking into account the eyes with CN cataract (Left). The eyes are also classified by groups using different colors (Right).

Now, it can be seen that correlations improve significantly if only one type of cataract (CN) is considered (parameters of correlation R^2 are much higher). This can be attributed to the different affectation that every kind of cataract has on the BSCVA and the OSI parameters, depending on its location in the crystalline lens.

The statistical analysis among groups in terms of BSCVA and OSI is performed again, but only taking into account eyes with CN cataracts. The obtained P values for BSCVA and OSI are shown in Tables 6 and 7, respectively.

BSCVA	**Control Group**	**Grad. 1**	**Grad. 2**	**Grad. 3**
Control Group	**-**	<0.01	<0.01	<0.01
Grad. 1	**-**	-	<0.01	<0.01
Grad. 2	**-**	-	-	<0.01
Grad. 3	**-**	-	-	-

Table 6: comparison of BSCVA between the different groups by paired simple *t* test (CN cataracts).

OSI	**Control Group**	**Grad. 1**	**Grad. 2**	**Grad. 3**
Control Group	**-**	<0.01	<0.01	<0.01
Grad. 1	**-**	-	0.06	<0.01
Grad. 2	**-**	-	-	0.05
Grad. 3	**-**	-	-	-

Table 7: comparison of OSI between the different groups by paired simple *t* test (CN cataracts).

Again, the differences found among groups are statistically significant when the BSCVA is compared. However, in this case the comparison in terms of OSI also provides statistically significant differences among the control groups and groups of cataract patients. The only exceptions are cataract groups Grad. 1 and 2 (P=0.06) and Grad. 2 and 3 (P=0.05), which have P values at the limit of the statistical significance.
Figures 10 and 11 show the OSI and the BSCVA values in increasing order for eyes with CN cataracts, codified by color depending on the group.

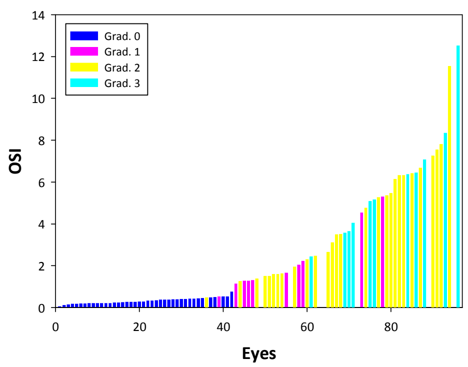

Figure 10: OSI parameter of all patients belonging to the different groups coded by color. Only patients with CN cataracts are shown.

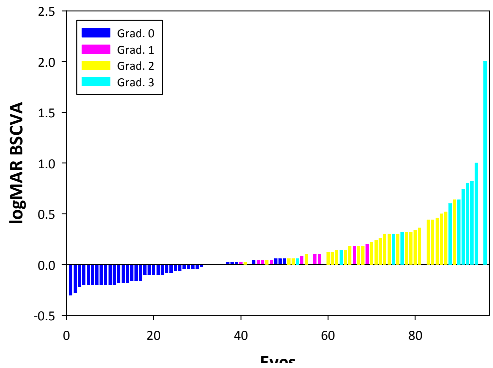

Figure 11: BSCVA parameter of all patients belonging to the different groups coded by color. Only patients with CN cataracts are shown.

It can be observed that cataracts in this case are better classified, especially when the OSI parameter is used. Nevertheless, some overlapping still remain among groups, which can have its origin in the subjective gradation made by the physicians, which can vary from one to another. Hence, the potentiality of this new objective tool in classifying cataracts. Because it is based on double-pass measurements, is does not need the active participation of the patient (as with the BSCVA measurement) neither the ophthalmologist expertise (as with the LOCS III gradation).

On the other hand, next figures (Figure 12 and 13) show the obtained correlations for patients with SCP cataracts.

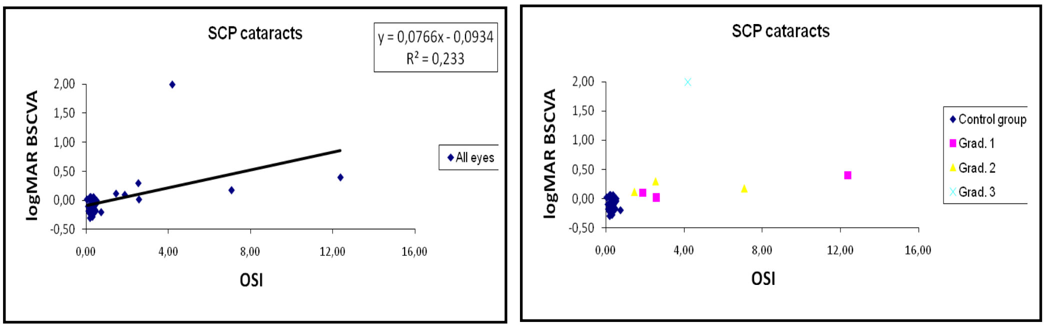

Figure 12: Correlation between BSCVA and OSI taking into account the eyes with SCP cataract (Left). The eyes are also classified by groups using different colors (Right).

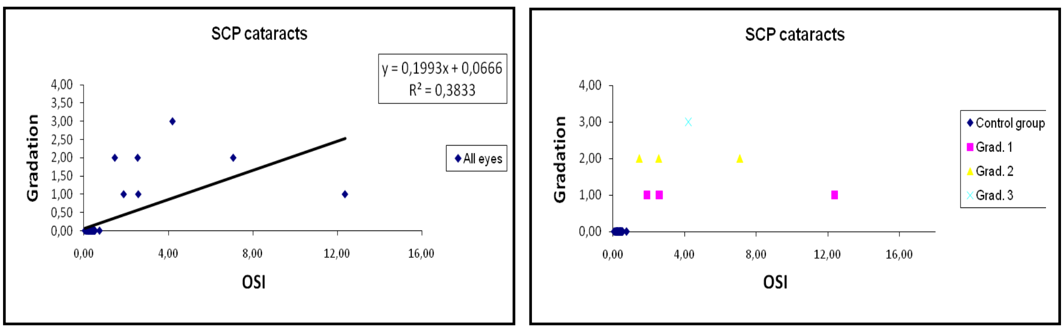

Figure 13: Correlation between cataract gradation and OSI taking into account the eyes with SCP cataract (Left). The eyes are also classified by groups using different colors (Right).

In this case, the number of patients is not large enough in order to extract conclusions of the results. The statistical analysis does not either report reliable results. Figures 14 and 15 illustrate the OSI and BSCVA for all eyes with SCP cataracts in increasing order. However, the lack of eyes with this kind of cataracts makes impossible to perform an analysis of the obtained results.

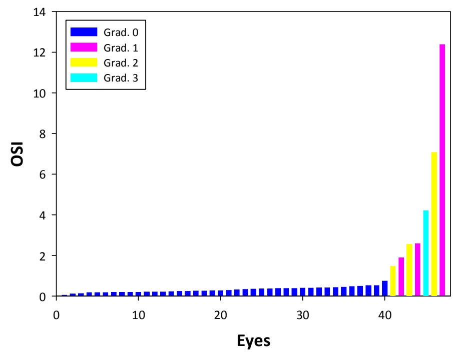

Figure 14: OSI parameter of all patients belonging to the different groups coded by color. Only patients with SCP cataracts are shown.

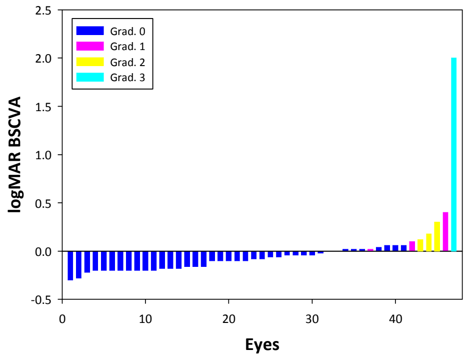

Figure 15: BSCVA parameter of all patients belonging to the different groups coded by color. Only patients with SCP cataracts are shown.

6. Conclusions

In this study, a new objective approach to assess cataracts based on double-pass measurements is presented. The method uses a new parameter called Optical Scatter Index (OSI), extracted from the retinal image, which accounts for the intraocular scattering present in the eye. In this study we analyzed 59 patients: 20 of them without cataracts (control group) and 39 with cataracts of different subjective degree (by ophthalmologist) and type.

The scatter index (OSI) provided a robust tool to objectively classify cataract patients. The mean OSI obtained in eyes without cataracts (control group) was always below 1. For incipient cataracts this value increased up to 2.62 ± 2,26 (Grad 1), meanwhile for intermediate cataracts it was 4.05 ± 2.66 (Grad 2). Finally, for mature cataracts the averaged OSI was 5.95 ± 2.95. This agrees with the results found in previous studies, were a smaller number of eyes was evaluated[13].

In most of the patients we found a good correlation between the values of OSI and BSCVA and the subjective cataract classification system derived from LOCS III, mainly if different kinds of cataracts are treated separately. So, it is necessary determine the kind of the cataract that patients have to obtain a good classification of its degree through OSI parameter. However, some noticeable differences between OSI and the other two subjective procedures suggest the convenience of using an objective parameter to establish the severity of the cataract and its actual impact on the retinal image and quality of vision.

This new objective parameter may be a quite valuable tool to make a sound decision on the convenience of scheduling the cataract surgery maximizing the benefit for the patient.

7. References

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