Light distortion and ocular scattering with glistening and aberration-free pseudophakic IOL: a pilot study

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PURPOSE: To evaluate two different methodologies for measuring intraocular light scattering and light disturbances in pseudophakic patients implanted with a monofocal aspheric intraocular lens (IOL).

SETTING: Clínica Oftalmológica Salgado Borges, Porto, Portugal.

METHODS: Eighteen consecutive patients (mean age: 70 ± 7 years, range: 60 to 86 years) with cataract were bilaterally implanted with an aspheric monofocal IOL (enVista™, Bausch & Lomb) by the same experienced surgeon. Examinations were performed 5 to 8 months after surgery. Objective ocular scattering index (OSI) for a 4 mm pupil, as well as other parameters related to the quality of vision through the ocular-IOL optical system were evaluated with the HD Analyzer® (Visiometrics, Spain) under non-dilated conditions. Light disturbances were evaluated with a prototype device (Light Distortion Analyzer [LDA], University of Minho, Portugal).

RESULTS: Average lens power was 21.40 ± 2.34 D, with a post-operative spherical equivalent refractive error of 0.14 ± 0.51 D of sphere and −0.18 ± 0.51 D of cylinder. Median value (minimum, maximum) for the OSI was 1.30 (0.3, 7.9), and for the light distortion index (LDI) was 23 (11.30, 90.80). LDI was positively correlated with the OSI (Rho = 0.563; p = 0.015), and negatively correlated with the modulation transfer function (MTF) cutoff frequency (Rho = 0.467; p = 0.049).

CONCLUSIONS: The HD Analyzer® and LDA may help in identifying tear film problems that could increase the overall OSI index in post-surgical patients undergoing cataract extraction with IOL implantation. Both instruments provide different information about the optical quality perceived by the patient.

J Emmetropia 2015; 3: 127-132

Submitted: 3/13/2015
Accepted: 6/16/2015

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Financial disclosure: JMGM, HN and SCP-M disclose that they are co-inventors in a patent application involving an experimental device used in this study.

Acknowledgements: This study has been funded by FEDER through the COMPETE Program, and by the Portuguese Foundation for Science and Technology (FCT) in the framework of projects PTDC/SAU-BEB/098391/2008, PTDC/SAU-BEB/098392/2008 and the Strategic Project PEST-C/FIS/UI607/2011. The authors would like to thank Bausch & Lomb for the loan of the HD Analyzer® used in the present study.

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Photic phenomena including dysphotopsia, glare, haloes and starbursts have been increasingly reported by patients who have undergone refractive surgery with multifocal intraocular lens (IOL) implantation for presbyopia correction. These phenomena usually represent distortions from light sources as light passes through irregular, non-transparent or specific optical prostheses. Since it is difficult to isolate the different components of these photic phenomena, the term “light distortion (LD)” will be used. Despite being subjective perceptions, clinicians and researchers have always been interested in quantifying these phenomena. Devices for evaluating photic phenomena on computer screens, psychophysical straylight meters and devices where the patient has to recognize letters surrounding a central source of glare have been developed. However, some of these methods can be time consuming, do not reflect real daily life conditions or cannot describe the size, shape and intensity of the disturbance under evaluation. Thus, their use in the clinical setting is limited.
Halometers instead are able to describe the shape and size of the disturbance. Some of the existing devices use video display units while others use physical light sources with a wider dynamic range in terms of intensity. Different devices have been used in recent years. Some use a central light source over a computer screen where peripheral stimuli are presented; others use a data show projector to project peripheral stimuli over a larger area around a strong central light source; and some, instead of peripheral punctual stimuli, use letters that the patient has to recognize. The aforementioned devices have various limitations, including the limited brightness emitted by computer screens, lack of reproducibility in the intensity and spectral characteristics of the sources when presented on computer screens and computer data show devices, and the need to recognize stimuli which might cause additional limitations in the performance of these tests, particularly in older patients. The Light Distortion Analyzer (LDA) was developed to overcome some of these limitations. The system comprises an electronic board with 1 central light source (Light Emitting Diode, LED) and 240 peripheral LEDs.

The aim of this study was to assess the optical quality through an objective scatter meter and a new psychophysical method that measures the size, shape and regularity of the LD surrounding an intense light source against a dark background.

**MATERIALS AND METHODS**

This was a prospective, cohort, case series involving 18 patients implanted with the enVista™ (B&L, Rochester, NY) acrylic aspheric monofocal intraocular lens (IOL) following cataract surgery. This IOL is a single-piece implant with two modified “C” haptics, a total length of 12.5 mm and an optical zone of 6 mm, with a square posterior edge (Figure 1). Due to the aspheric lens optics, this lens is free from induced aberrations, and the manufacturer claims it is made of a glistening-free hydrophobic acrylic material. Patients included 12 men and 6 women with a mean age of 70 ± 7 years (60 to 86 years). Only the patient’s right eye was assessed in this study. All lenses were implanted by the same experienced surgeon (JS-B) through a 2.2 mm incision following the usual procedures for cataract extraction with pseudophakic IOL implantation.

Intraocular light scattering was obtained with a newer version of the Optical Quality Analysis System (HD Analyzer v1.0, Visiometrics, Spain). Optical quality and ocular scattering index (OSI) were obtained for each eye (Figure 2a). According to the manufacturer, the Scatter Meter system allows intraocular scattered light quantification, while the Optical Quality

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**Figure 1.** enVista™ lens design.

**Figure 2.** (A) Output of the HD Analyzer® reporting an OSI of 4.5; and (B) output of the LDA system showing an LDI of 42.34%. The exams do not correspond to the same patient.
system provides information about the optical quality evaluation for distance vision. Both systems capture six double-pass images under best spherical correction conditions (distance vision), and process them. LD was measured with an experimental Light Distortion Analyzer (LDA), which is a psychophysical method for evaluating the size, shape, location and irregularity of the LD surrounding an intense light source against a dark background from a distance of 2.0 meters. The device has a central 5 mm light-emitting diode (LED) acting as source of light/glare and 240 peripheral small (1 mm) LEDs. The peripheral stimuli turn on and off randomly along a given semi-meridian. The patient provides feedback to the system when the peripheral stimuli are seen around the central light source and its surrounding distortion (Figure 2b). It takes about 90 seconds to perform a full measurement in one eye. A more comprehensive description of the device and its radiometric characterization of the hardware has been presented elsewhere.

### Table 1. Demographics of the sample included in this study.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Median</th>
<th>Variance</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Age (years)</td>
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<td>69.00</td>
<td>55.27</td>
<td>60.00</td>
<td>86.00</td>
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<tr>
<td>VA (logMAR)</td>
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<td>0.00</td>
<td>0.067</td>
<td>0.00</td>
<td>1.10</td>
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<tr>
<td>IOL Power</td>
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<td>21.25</td>
<td>8.74</td>
<td>15.00</td>
<td>26.00</td>
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<tr>
<td>M</td>
<td>18</td>
<td>0.00</td>
<td>0.35</td>
<td>−1.00</td>
<td>1.25</td>
</tr>
<tr>
<td>J0</td>
<td>18</td>
<td>0.00</td>
<td>0.04</td>
<td>−0.35</td>
<td>0.38</td>
</tr>
<tr>
<td>J45</td>
<td>18</td>
<td>0.00</td>
<td>0.03</td>
<td>−0.46</td>
<td>0.50</td>
</tr>
<tr>
<td>HD Analyzer® Measured Pupil</td>
<td>18</td>
<td>4.35</td>
<td>2.40</td>
<td>3.10</td>
<td>5.50</td>
</tr>
</tbody>
</table>

VA: visual acuity; IOL: intra-ocular lens; M: spherical equivalent; J0 and J45: horizontal and oblique vectorial components of astigmatism.

### Table 2. Optical quality (OQ) results from the HD Analyzer® derived for the patient measured pupil.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Median</th>
<th>Variance</th>
<th>Minimum</th>
<th>Maximum</th>
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<tr>
<td>OQ Profile Width 50%</td>
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<td>4.54</td>
<td>15.74</td>
<td>2.36</td>
<td>17.22</td>
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<tr>
<td>OQ Profile Width 10%</td>
<td>18</td>
<td>16.03</td>
<td>166.4</td>
<td>0.00</td>
<td>49.20</td>
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<td>OQ MTF VA 100%</td>
<td>18</td>
<td>0.80</td>
<td>0.21</td>
<td>0.10</td>
<td>1.82</td>
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<tr>
<td>OQ MTF VA 20%</td>
<td>18</td>
<td>0.56</td>
<td>0.10</td>
<td>0.20</td>
<td>1.43</td>
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<tr>
<td>OQ MTF VA 9%</td>
<td>18</td>
<td>0.30</td>
<td>0.02</td>
<td>0.10</td>
<td>0.80</td>
</tr>
<tr>
<td>OQ Strehl Ratio</td>
<td>18</td>
<td>0.15</td>
<td>0.04</td>
<td>0.07</td>
<td>0.94</td>
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<tr>
<td>OQ MTF Cutoff (cpd)</td>
<td>18</td>
<td>26.92</td>
<td>153.26</td>
<td>7.60</td>
<td>53.04</td>
</tr>
</tbody>
</table>

VA: visual acuity; MTF: modulation transfer function; cpd: cycles per degree.

### Table 3. Scatter Meter (SCT) results from the HD Analyzer® derived for a 4 mm pupil.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Median</th>
<th>Variance</th>
<th>Minimum</th>
<th>Maximum</th>
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</thead>
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<tr>
<td>SCT_OSI</td>
<td>18</td>
<td>1.30</td>
<td>4.84</td>
<td>0.30</td>
<td>7.90</td>
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<td>SCT Profile Width 50%</td>
<td>18</td>
<td>3.64</td>
<td>17.71</td>
<td>2.44</td>
<td>17.63</td>
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<td>SCT Profile Width 10%</td>
<td>18</td>
<td>13.26</td>
<td>100.95</td>
<td>0.00</td>
<td>37.05</td>
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<tr>
<td>SCT MTF VA 100%</td>
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<td>1.06</td>
<td>0.20</td>
<td>0.30</td>
<td>1.67</td>
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<tr>
<td>SCT MTF VA 20%</td>
<td>18</td>
<td>0.65</td>
<td>0.12</td>
<td>0.20</td>
<td>1.33</td>
</tr>
<tr>
<td>SCT MTF VA 9%</td>
<td>18</td>
<td>0.40</td>
<td>0.04</td>
<td>0.10</td>
<td>0.91</td>
</tr>
<tr>
<td>SCT Strehl Ratio</td>
<td>18</td>
<td>0.16</td>
<td>0.003</td>
<td>0.07</td>
<td>0.21</td>
</tr>
<tr>
<td>SCT MTF Cutoff (cpd)</td>
<td>18</td>
<td>31.99</td>
<td>181.96</td>
<td>7.51</td>
<td>51.90</td>
</tr>
</tbody>
</table>

OSI: ocular scattering index; VA: visual acuity; MTF: modulation transfer function; cpd: cycles per degree.
previously published. The system produces different measurements of size, shape, location and regularity of the LD surrounding a bright light source.

Statistical analysis was performed using SPSS v21.0 (IBM Inc. IL, USA). Considering the limited sample size and non-normal distribution expected for the LD parameters, non-parametric statistics were applied. Descriptive statistics were obtained from LD data and scatter measurements, and correlations between LD and scatter were evaluated using Spearman’s Rho coefficient. The level of statistical significance was set at $p < 0.05$.

**RESULTS**

The average power of the lenses was $21.40 \pm 2.34$D, with a post-operative spherical equivalent refractive error of $0.14 \pm 0.51$D of sphere and $-0.18 \pm 0.51$D of cylinder. Patient demographics are presented in Table 1.

The parameters derived from the optical quality and scatter meter of the HD Analyzer® system are shown in tables 2 and 3, respectively. Parameters reported include the width of the point spread function (PSF) at 50% and 10% of the maximum value (Profile width 50% and 10%, respectively), the predicted visual acuity (VA) based on the modulation transfer function (MTF) for 100%, 20% and 9% contrast (MTF VA 100%, MTF VA 20% and MTF VA 9%, respectively), the Strehl ratio and the MTF cutoff frequency. All parameters were presented for the optical quality (OQ) and scatter meter (SCT) measurement procedures. Table 3 also shows the OSI value.

Table 4 shows the values obtained from the LDA system for size (LDI and BFCRad), location (X, Y coordinates and orientation) and regularity (BFCIrreg and BFCIrregSD) of the LD.

LDI and OSI were positively correlated ($Rho = 0.563; p = 0.015$), while LDI and the MTF cutoff frequency were negatively correlated ($Rho = -0.467; p = 0.049$) (Figure 3).

**DISCUSSION**

The present study shows that pseudophakic patients implanted with aspheric IOLs recover their optical quality almost to levels of non-cataract pre-presbyopic patients. We obtained OSI results consistent with those reported by Artal et al. in a control population without cataract in a recent study involving a cohort of patients with age and refractive error similar to that of patients enrolled in our study. The LDI values found in our study are comparable to those from a control population used by Brito et al. to evaluate the effect of multifocal IOL on LDI.

We measured the optical quality using two methods. The HD Analyzer® is an optical instrument that measures the scattering of the PSF to objectively quantify the optical quality of the eye as it is observed by the instrument in a double-pass technique. In the pseudophakic eye, this function may be altered by opacities of the ocular media, including the capsular bag and IOL. Unlike previous...
studies published, we have reported the optical quality and scatter meter results. According to the manufacturer, and the definition of OSI parameter, the measurement is performed using a 4 mm artificial pupil. The values obtained for estimated VA for different contrasts (9%, 20%, 100%), and the width of the PSF at 10% and 50% high follow the same trend, but are slightly higher for the scatter meter-derived measurements as a result of a slightly larger pupil of 4.35 mm, compared with the 4.00 mm of the Optical Quality-derived metrics.

The Strehl ratio and MTF cutoff values suggest that patients implanted with the IOL have recovered an optical quality comparable to that of a healthy adult population. In previous studies including adults implanted with posterior chamber phakic IOLs (mean age of 36 years), Kamiya et al. reported a cutoff frequency of 30.4 cpd for the control group and 28.7 cpd for patients implanted with the IOL. With respect to the Strehl ratio, they reported 0.18 and 0.17 in both groups, respectively. Furthermore, the HD Analyzer predicted a VA of 0.80 and 1.00 for both groups for 20% and 100% contrast conditions, respectively; OSI in their study were 1.03 and 1.06, respectively. The same authors reported lower values in patients who had undergone intra-corneal lenticule extraction for refractive correction using the VisuMax platform (Carl Zeiss, Meditec AG). To our knowledge, this is the first study reporting HD Analyzer optical quality parameters with the enVista IOL after cataract surgery. The results of this pilot study compare well with those reported by previous authors in other younger populations subjected to refractive procedures, although slightly lower than young controls in the same studies. The slight reduction in MTF cutoff frequency compared to younger patients might be explained by the age of our subjects (cataract patients) compared to that of the control groups. Tear film quality in older patients could affect the post-cataract quality of vision.

The LDA instrument quantifies the limit of the LD induced by the optics of the eye as it is viewed by the patient. Despite the optical quality observed with the HD Analyzer, the LDA values were slightly higher than those that might be expected in young controls. In a previous study (unpublished data), we observed a median distortion index of 15% in presbyopic patients before multifocal contact lens fitting. Patients in that study were significantly younger than those in the present cohort, and had no clinical cataract. Our results are consistent with those obtained by Brito et al. with the same LDA instrument in 9 patients implanted with an aspheric Tecnis 1-piece (AMO) IOL after cataract extraction in a population with a median age of 63 years. We obtained a median cutoff frequency of 28 cpd, which is very close to the post-surgical values found by Kamiya et al. 3 months after phakic IOL implantation, and 6 months after intra-corneal lenticule extraction for refractive correction.

A limitation of the present study is the lack of a control group implanted with a non-spherical IOL. Despite this, we might expect a slightly larger post-operative positive spherical aberration with a spherical IOL as a control group. The small sample size is also a limitation. Nevertheless, we observed that in the absence of post-operative complications after cataract with aspheric IOL implantation, patients recover their visual function to limits comparable to the healthy adult population. This included objective assessment of the optical quality of the ocular media and the perception of the light disturbance by the patient measured with the new psychophysical device.

In summary, the HD Analyzer and the LDA provide information about different aspects of visual function in pseudophakic patients. Further studies considering larger samples are necessary in order to evaluate the role of both examinations in the assessment of the optical quality of the eye after cataract extraction with IOL implantation.

REFERENCES


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