Macular Disease Affects the Outcome of ZyWave™ Aberrometry

Siamak Zarei-Ghanavati, MD; Touka Banaee, MD; Mojtaba Abrishami, MD; Ali Dehghani, MD

BACKGROUND AND OBJECTIVE: Wavefront analysis aims to measure aberrations in the eye, often before and after surgeries. The Hartmann–Shack instrument is an outgoing reflective aberrometer that uses a laser light source. The authors aimed to evaluate changes in aberrations of the eyes with macular irregularity by comparing with the fellow normal eyes.

PATIENTS AND METHODS: In a prospective study, the authors evaluated both eyes of patients with unilateral acquired foveal lesion by ZyWave (ZyWave; Milwaukee, WI) aberrometer. Eighteen eyes of 9 patients with a mean age of 32 years were examined.

RESULTS: After exclusion of two cases with central serous chorioretinopathy (due to smooth macular surface), a statistically significant increase in higher-order aberration in the involved eyes compared with the normal fellow eyes ($P = .043$) was found. There was also a statistically significant increase in horizontal trefoil in the involved eyes compared with normal eyes ($P = .04$).

CONCLUSION: This fellow eye study shows that macular irregularity might increase high-order aberrations measured by the Hartmann–Shack aberrometer.

[Introduction: Wavefront analysis aims to measure aberrations in the eye, often before and after surgeries. Several systems have been developed as clinical tools for wavefront aberrometry in recent years, one of which is the Hartmann–Shack aberrometer. The Hartmann–Shack instrument is an outgoing reflective aberrometer that uses a laser light source working in the near infrared. It is focused toward the fovea through spherical lenses. Then, the reflected light from the fovea passes through the ocular media (eye optics) and this outgoing wavefront hits the Hartmann–Shack sensor and is divided into several light points by a micro-lens array. Finally, the pattern of the wavefront is captured with a charge coupled device and...]

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is analyzed. The analyzed wavefront corresponds to the effect of all components of the ocular media on the reflected light. Optical media of the eye consists of tear film, cornea, lens, and vitreous. Several studies have shown that changes in these components can result in ocular aberrations.1-3

Review of the Hartmann–Shack aberrometer principles raises a question: does macular irregularity, as a reflective surface and the reference source of outgoing light that is analyzed for wavefront measurements by the Hartmann–Shack instrument, have any effect on the aberration pattern?

The purpose of this study is to evaluate changes in aberrations of the eyes with macular irregularity and to compare them with the fellow normal eyes.

**PATIENTS AND METHODS**

In a prospective study from January to May 2009, we assessed both eyes of patients with unilateral acquired foveal lesion who presented to Khatam-al-Anbia Eye Center (Mashhad, Iran). Patients with a history of ocular surgery were excluded. In addition, we excluded patients with congenital or childhood macular disease to avoid the possible effect of macular disease on the growth of the eye.4

Comprehensive ophthalmic examination was done for all patients, including uncorrected and best-corrected visual acuity measurement, tonometry, slit-lamp biomicroscopy, and dilated fundus examination. Topography was performed to evaluate corneal abnormality. Patients with any change in ocular media (corneal scar, keratoconus, cataract, vitreous opacity, etc.) were excluded from the study.

Before measurement, the eye was cyclopleged with tropicamide 1%. Wavefront measurements were performed with ZyWave aberrometer (Bausch & Lomb, Technolas, NY). Each eye was evaluated three times and aberration was measured in a 6-mm optical zone. Whole-eye wavefront sensing was used for assessing macular disease-induced aberrations. The Zernike coefficients were determined up to the fifth order and root mean square (RMS) of total and higher order aberrations, horizontal and vertical coma, horizontal and vertical trefoil, and spherical aberration were compared between the two eyes. Enantiomorphism was neutralized by inverting the sign of mirror-symmetric coefficients of left eyes.5

Statistical testing was performed by using the SPSS Windows version 16 (SPSS, Inc., Chicago, IL). The variables are expressed as mean ± standard deviation and the t test was used to compare differences. Differences were considered significant at a P value of .05 or less.

**RESULTS**

In this study, 18 eyes of 9 patients (2 women and 7 men) with a mean age of 32 years (range: 19 to 41 years) were examined. All patients had one eye affected with macular disease, including choroidal neovascularization (2 cases), macular hole (1 case), macular scar (3 cases), cystoid macular edema (1 case), and central serous chorioretinopathy (2 cases). Mean best-corrected visual acuity was 20/20 (range: 20/30 to 20/15) in normal eyes and 20/200 (range: 20/100 to 20/500) in the involved eyes (Table). Mean sphere was +0.50 diopters (D) (range: -1.25 to +4.50 D) and +0.75 D (range: -1.00 to +3.50 D), and mean cylinder was -1.28 D (range: -0.25 to -4.50 D) and -1.48 D (range: -0.00 to -4.00 D) in normal eyes and involved fellow eyes, respectively.

Mean total aberrations in involved and normal eyes were $2.45 ± 1.46\,\mu m$ and $1.85 ± 1.08\,\mu m$, respectively ($P = .09$). RMS of higher-order aberrations in involved and control normal eyes were $0.63 ± 0.35\,\mu m$ and $0.49 ± 0.12\,\mu m$, respectively ($P = .24$). Although higher-order aberrations were increased in the involved eyes, there was not a statistically significant difference between the

<table>
<thead>
<tr>
<th>Aberration</th>
<th>Normal Fellow Eyes (µm)$^b$</th>
<th>Involved Eyes (µm)$^b$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total HOA</td>
<td>0.49 ± 0.12</td>
<td>0.73 ± 0.26</td>
<td>.04$^d$</td>
</tr>
<tr>
<td>Spherical</td>
<td>0.10 ± 0.31</td>
<td>0.11 ± 0.24</td>
<td>.88</td>
</tr>
<tr>
<td>H-Coma</td>
<td>0.22 ± 0.34</td>
<td>0.10 ± 0.24</td>
<td>.35</td>
</tr>
<tr>
<td>V-Coma</td>
<td>-0.03 ± 0.33</td>
<td>0.11 ± 0.15</td>
<td>.14</td>
</tr>
<tr>
<td>H-Trefoil</td>
<td>-0.10 ± 0.17</td>
<td>0.06 ± 0.06</td>
<td>.04$^d$</td>
</tr>
<tr>
<td>V-Trefoil</td>
<td>0.28 ± 0.30</td>
<td>0.14 ± 0.19</td>
<td>.14</td>
</tr>
</tbody>
</table>

HOA = higher-order aberrations; H = horizontal; V = vertical.
$^a$After exclusion of two cases with central serous chorioretinopathy.
$^b$Values given as mean ± standard deviation.
$^c$Statistically significant.
normal and involved eyes. When we excluded the two patients with central serous chorioretinopathy (due to lack of irregularity at the inner macular surface), the difference became statistically significant (0.49 ± 0.12 vs 0.73 ± 0.26 µm, \(P = .04\)).

We also found a statistically significant increase in horizontal trefoil in the group of involved eyes compared with normal eyes (-0.10 ± 0.17 vs 0.06 ± 0.06 µm, \(P = .04\)). No significant differences were noted in the mean values of other aberrations, including horizontal coma (0.22 ± 0.34 vs 0.10 ± 0.24 µm, \(P = .35\)), vertical coma (-0.03 ± 0.33 vs 0.11 ± 0.15 µm, \(P = .14\)), vertical trefoil (0.28 ± 0.30 vs 0.14 ± 0.19 µm, \(P = .14\)), and spherical aberration (0.11 ± 0.24 vs 0.10 ± 0.31 µm, \(P = .88\)) between involved and normal eye groups (Table).

**DISCUSSION**

Although several studies were designed to explore the contribution of any part of ocular media (tear film, cornea, lens, and vitreous) to the total aberrations,\(^6\)\(^-\)\(^10\) our knowledge about the effect of macular irregularity on ocular aberrations is limited.

Numerous designs of aberrometers are now available, including Tscherning, Ray tracing, Skiascopy, and Hartmann–Shack. The ZyWave aberrometer measures a wavefront on the basis of the Hartmann–Shack principle. As previously mentioned, a narrow beam of coherent monochromatic light (around 1 mm wide) is centered in the fovea. Approximately 1% of the incident light is reflected as a quasi-point source of light. Although the point is small, it is not a mathematical point and has a 50- to 100-µm diameter. Therefore, any irregularity in the macula, as a focal point of incident light, might cause distortion in the reflected light. This means that macular irregularity may cause the wavefront to leave the eye because it is not plane in shape (Fig. 1A); therefore, the wavefront aberrometer will report high-order aberrations. For example, if two parts of this reflecting surface have 50 µm difference in height, the two sides of the reflected wavefront will have 50 µm acceleration or retardation in comparison to each other at the beginning (Fig. 1B). This acceleration/retardation will change after passing through ocular media and will affect the shape of the analyzed wavefront.

Quality of the analyzed wavefront is another issue. Loss of the quality of the exiting light occurs because of diffuse reflection (in contrast with specular reflection) from the macular plane (Fig. 1C). An uneven macular topography may affect the quality of the single laser spot and therefore produce more noise and interfere with the spot center detection algorithm of the sensor. This is likely for the ZyWave aberrometer because of its low number of spots.

Another possibility is that a patient with macular irregularity might have an eccentric fixation. Therefore, both incident and reflected light passes off axis through the optical system of the eye. This decentration might cause more aberrations (Figs. 1D and 1E). In patients with macular irregularity, tilt of the irregular, reflecting plane (macula) regarding the incident light might also cause more distortion of the reflected light. In other words, in the normal macula, the plane of the reflecting...
surface (macula) is smooth and perpendicular to the incoming light, but in the case of macular irregularity, eccentric fixation causes this irregular plane to be tilted; therefore, aberration will increase.

Consistent with these hypotheses, we found significant increases in RMS of higher-order aberrations and horizontal trefoil in eyes with macular disease compared with normal fellow eyes (Table).

Figure 2 shows the OCT and higher-order aberrometry maps of two patients with macular disease. Interestingly, in the first patient, higher-order aberrations in the eye with macular lesion are not more than the fellow eye. This case was diagnosed as having central serous chorioretinopathy. OCT captured from the involved eye showed dome-shaped elevation of the fovea with regular and smooth surfaces. Although the position of the reference point is changed, the smoothness of the inner macular surface describes why the reflected light is not distorted. Anterior-posterior change in the location of the focal plane induces defocus (a lower-order aberration) and, in this case, anterior displacement of the focal point resulted in hyperopic defocus in the involved eye, which caused a difference in second-order aberrations in comparison with the fellow eye. In the other case, OCT maps of the involved eyes demonstrated severe macular irregularity and higher-order aberrations maps show significant distortion in the involved eye compared with the normal fellow eye.

Bessho et al.\textsuperscript{11} compared the higher-order aberrations in patients with and without macular disease. They used the Tracey Visual Function Analyzer (Tracey Technologies, Houston, TX), which works based on the ray-tracing principle, and showed that higher-order aberrations in eyes with macular disease are greater than normal eyes. However, this study has some limitations. First, cataract surgery has different and variable effects on ocular aberrations\textsuperscript{12-14} and the large number of pseudophakic eyes in the Bessho et al.\textsuperscript{11} study might work as a confounding factor. Second, inclusion of a wide age range might also have resulted in unexpected age-induced aberrations in their study groups.

We used the normal fellow eyes of the same patients as controls for comparing the high-order aberrations. In addition, the range of age was limited in our study (19 to 41 years). This made the results of our study reliable. Although the results of ocular aberrations in the Bessho et al.\textsuperscript{11} study measured by a ray-tracing system could not be generalized to other aberrometry systems, we reached similar results and found that there is an increase in higher-order aberrations in eyes with macular disease compared with normal fellow eyes. Further studies with a larger sample size and more varied types of macular lesions are needed to precisely answer our study question.

REFERENCES
