Metamorphopsia Assessment before and after Vitrectomy for Macular Hole

Kristian Kroyer, Ulrik Christensen, Morten la Cour, and Michael Larsen

PURPOSE. To evaluate the degree of metamorphopsia in 42 patients before and 6 months after vitrectomy for idiopathic unilateral macular hole.

METHODS. Semicircular test and reference stimuli of variable diameters were applied in a binocular test that measured interocular size disparity in patients with unilateral macular hole. The test was applied 1 day before surgery and repeated after 6 months.

RESULTS. Before surgery, mean disparity was 0.34° at 1° visual field eccentricity declining to a plateau value of approximately 0.2° between 3° and 5° of eccentricity. Six months after successful hole closure, interocular disparity was practically constant, with a median disparity below 0.1 and no significant effect of eccentricity. Baseline interocular disparities lower than 0.35° at 1° eccentricity were associated with nine EDTRS letters of better visual outcome compared with higher disparities (P < 0.001).

CONCLUSIONS. Metamorphopsia was consistently reduced after macular hole surgery, supporting that the intervention was successful in repositioning displaced photoreceptors toward their original location. Final best corrected visual acuity was related to the degree of preoperative disparity in spatial projection between receptive units with a shared perceptual projection in visual space in the two eyes. (ClinicalTrials.gov number, NCT00302328) (Invest Ophtalmol Vis Sci. 2009;50:5511–5515). DOI: 10.1167/iovs.09-3530

Visual spatial distortion, metamorphopsia, and reduced visual acuity are features of retinal diseases that distort the photoreceptor mosaic. During the formation of an idiopathic macular hole, a localized circular displacement toward a more peripheral location occurs around a point in or near the center of the foveola, the pattern of displacement being a regular and circular one. The hole appears to form spontaneously, and the condition predominantly affects women above the age of 60.

In the treatment of macular hole, the therapeutic goal is to improve visual acuity and relieve metamorphopsia, the latter being a major source of dysfunction because it disturbs binocular vision. It has actually been suggested that removal or reduction of metamorphopsia correlates more closely with the likelihood of a perceived successful outcome than does the improvement in Snellen acuity.

In addition to Amsler grid testing, at least five other psychophysical tests have been applied in the assessment of metamorphopsia in patients with macular hole. Nevertheless, objective methods of metamorphopsia assessment have rarely been included in interventional studies of macular hole.

A classic qualitative metamorphopsia test used in the diagnosis of macular hole, the Watzke-Allen test, requires the patient to describe the appearance of a rectangular, illuminated field projected on the patient’s fundus and centered on the macular hole during slit lamp biomicroscopy. A similar approach is used in the Line Resolution Test, in which the subject has to decide for each pair of a series of line pairs, which line is distorted.

Binocular perimetry was developed to assess photoreceptor displacement in patients with macular hole. The method maps metamorphopsia in subjects with a unilateral macular hole and a normal fellow eye by applying dichoptic stimuli to map corresponding retinal locations.

M-CHARTS (Inami Co., Tokyo, Japan) can be been used to evaluate patients with macular hole based on monocular testing using a hyperacuity (Vernier acuity) stimulus. Preview-PHP (Carl Zeiss Meditec, Jena, Germany) is another test based on a hyperacuity approach that was originally designed to assess metamorphopsia in AMD, but has been used also to detect metamorphopsia in eyes with macular hole. Assessment of metamorphopsia before and after surgical treatment for macular hole has only been made using a binocular perimetry technique reported by Jensen and Larsen and M-CHARTS. In contrast to the method used in the present study, these methods are not capable of measuring metamorphopsia as a function of visual field eccentricity.

We have recently introduced a metamorphopsia test designed specifically for the quantification of visuospatial distortion in patients with unilateral macular hole. The test measures visuospatial distortion as a function of eccentricity within the central 10° of the visual field, assuming an underlying circular pattern of photoreceptor displacement. In the prospective study presented herein, we assessed metamorphopsia in relation to visual field eccentricity before and after vitrectomy in 42 patients with idiopathic unilateral macular hole, to evaluate the degree of photoreceptor displacement after surgery and to determine the predictive value of preoperative metamorphopsia for predicting postoperative visual function.

METHODS

Subjects

Study participants were recruited from the Copenhagen Macular Hole (COMAH) study, a randomized, controlled clinical trial comparing different methods of surgical treatment for macular hole. Inclusion criteria were having a unilateral idiopathic macular hole Gass stage 2 or...
were studied before and after treatment. The standardized surgical
was presented to the patient and answered before the baseline exam-
nation during 10 hours per day for 5 days after surgery.
received by the eye having a macular hole is smaller than the image
to be of equal size.
unilateral macular hole, the patient will see two unevenly sized half-
cially into two halves of equal size but different color. If the rim of the
nia, the two disks combine to form a single round disk divided verti-
stimuli consist of two half-disks of different color presented dichopti-
The details of the retinal aniseikonia test have been described. 9 Test
Quantification of Metamorphopsia
All patients who were phakic at inclusion underwent phacoemulsification
with pseudophakic lens implantation 1 month before the baseline
examination. The minimum inner diameter of the hole (minimum
diameter) and the hole diameter at the level of the retinal pigment
epithelium (maximum diameter) were measured with the built-in
calipers of the system software. 10 In addition, patients completed a
visual function questionnaire designed for the study. The questionnaire
was presented to the patient and answered before the baseline ex-
amination.
All patients underwent surgical treatment for macular hole and
were studied before and after treatment. The standardized surgical
procedure included pars plana vitrectomy, removal of the posterior
hyaloid, fluid-gas exchange using C3F8 gas, and randomized assign-
ment to plain vitrectomy or vitrectomy with internal limiting mem-
brane (ILM) peeling, the latter subgroup again being randomized to
vital dye staining with indocyanine green or trypan blue. Comparison
of outcome for the different surgical subgroups is published in a
separate article.11 Patients were asked to maintain face-down position-
during 10 hours per day for 5 days after surgery.
The study enrolled 55 patients with a unilateral stage 2 (n = 19) or
stage 3 (n = 36) macular hole. Preoperative interocular disparity
findings in these 55 patients have been published.9 Thirteen patients
were excluded for various reasons: three did not achieve macular hole
closure, one developed a macular hole in the fellow eye, six were
unavailable for planned follow-up because of late enrollment, one
withdrew from the study, and two did not undergo differential perim-
etry testing because of instrument failure. With the exclusion of the 13
patients, the present analysis includes 42 eyes in 42 patients.
All participants gave written informed consent before inclusion.
The study was approved by the medical ethics committee of Copen-
hagen County (KA04144) and registered with the National Institutes
of Health as a clinical trial. The study was conducted according to the
Declaration of Helsinki.
Quantification of Metamorphopsia
The details of the retinal aniseikonia test have been described.9 Test
stimuli consist of two half-disks of different color presented dichopti-
cally to the test participant wearing red and green filter glasses, one
color for either eye. When seen by a healthy subject without aniseiko-
nia, the two disks combine to form a single round disk divided verti-
cally into two halves of equal size but different color. If the rim of the
half-disks seen by the diseased eye is located at an eccentricity affected
by metamorphopsia and micropsia produced by a centrosymmetric
unilateral macular hole, the patient will see two unevenly sized half-
disks. An operator then presents a series of combinations of unevenly
and evenly sized half-disks and records the combinations that appear to
the patient to form an intact and perfect disk, the two halves appearing
to be of equal size.
Micropsia is experienced by the patient because the image per-
ceived by the eye having a macular hole is smaller than the image
perceived by the normal fellow eye. the reference eye. This difference
in perceived size is used in the test where the reference eccentricity
is defined as the angular distance from the point of fixation to the rim
of the reference stimulus presented to the normal eye. The test deter-
mines the eccentricity required for a test stimulus (presented to the
diseased eye), to perceptually match the reference stimulus (presented
to the normal eye). This difference in eccentricity is referred to as
interocular disparity and will be used synonymously with metamor-
phopsia throughout this article, although, in principle, metamorphop-
sia can be both monocular and binocular. In the present context, we
define the metamorphopsia function as interocular disparity in rela-
tion to the eccentricity of the rim of the reference stimulus.
patients with a unilateral macular hole concentric with the premorbid center of
the fovea, interocular disparity is an angular measure of the radial
displacement of photoreceptors away from the center of the foveola.
The reference stimuli’s diameter ranged from 2° to 10°, in incre-
ments of 2° (Fig. 1). This corresponds to radial eccentricities of 1° to
5°. Although smaller reference stimuli were possible indeed, smaller
stimuli are often invisible to the eye with macular hole because their
projection on the fundus fell entirely inside the physical defect in the
retina. Test stimuli ranged from being identical with the reference
stimulus to an additional width of up to 1.5°. One degree of visual
angle is equal to 288 μm on the retina in the emmetropic eye.12 The
total number of half-disk combinations was 20 pairs of red and green
semicircular half disks, which were presented in random order at two
sessions on the same day with a short break between the two test
sessions.
Data analysis was based on average responses during the two
same-day sessions. The Mann-Whitney rank sum test was used to
compare metamorphopsia parameters before and after treatment. One-
way analysis of variance was used to describe the effect of eccentricity
on interocular disparity.
Results
The study population of patients with unilateral stage 2 or 3
macular hole tested immediately after and 6 months after
surgery comprised 42 patients with a mean preoperative best
corrected visual acuity in the macular hole eye of 51 ± 6 SD

Figure 1. Area of examination. Fundus photograph of macular hole with superimposed 2°, 4°, 6°, 8°, and 10° circles indicating the area of examination.
The mean postoperative visual acuity was 68/90 SD (range, 46–86 EDTRS letters). Preoperative interocular disparity was found to decrease with increasing eccentricity ($P < 0.001$), from a mean of 0.34° closest to the fovea, at 1° eccentricity, to a plateau of 0.2° at an eccentricity of 3° to 5° (Fig. 2).

Six months after successful macular hole closure, the 42 patients demonstrated an interocular disparity that was independent of eccentricity ($P = 0.962$) and had a mean disparity below 0.1° (Fig. 2). Error bars, SD.

The maximum preoperative interocular disparity was higher than 0.125° in all patients and had a mean value of 0.35° (Fig. 3). After surgery, no interocular disparity was detected in 10 eyes, the mean value for the entire study population of 42 patients being 0.13° (Fig. 3). Surgery was associated with no change in maximum disparity in four patients, all of whom had a baseline maximum disparity of 0.25 or higher (Fig. 3).

Disparity was decreased in at least one or more eccentricities in all patients. Nine patients even demonstrated negative disparities corresponding to macropsia (range, $-0.0625$ to $-0.25°$) at some eccentricities, but no patient had consistent macropsia at all eccentricities.

Examination of postoperative retinal ultrastructure with optical coherence tomography demonstrated discontinuities in the photoreceptor layer in 13 of 42 eyes. No correlation was found between this feature and interocular disparity at 1° eccentricity ($\chi^2 = 1952$ with 1 df; $P = 0.0162$) or visual acuity (mean 64 vs. 69 ETDRS letters; $P = 0.08$).

A post hoc analysis of baseline interocular disparity at 1° eccentricity demonstrated that when patients were stratified by disparity, 0.35° versus <0.35°, the former achieved better final visual acuity than the latter (mean, 73 ETDRS letters vs. 64 ETDRS letters).

### TABLE 1. Characteristics of Patients with Unilateral Macular Hole and a Healthy Fellow Eye

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Age, y</td>
<td>Range 54–78</td>
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<tr>
<td></td>
<td>Mean ± SD 67 ± 6</td>
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<tr>
<td>Sex</td>
<td>Male 6</td>
</tr>
<tr>
<td></td>
<td>Female 36</td>
</tr>
<tr>
<td>Spherical equivalent in study eye</td>
<td>Range $-4.6$ to 1.8</td>
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<tr>
<td></td>
<td>Mean ± SD $-1.1$ ± 1.3</td>
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<td>Lens status</td>
<td>Phakic 0</td>
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<tr>
<td></td>
<td>Pseudophakic 42</td>
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<tr>
<td>Preoperative visual acuity study eye (ETDRS-letters)</td>
<td>Range 37–67</td>
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<tr>
<td></td>
<td>Mean ± SD 51 ± 6</td>
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<tr>
<td>Preoperative visual acuity control eye (ETDRS-letters)</td>
<td>Range 69–98</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD 85 ± 5</td>
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<td>Visual symptoms in daily activities (41 responders)</td>
<td>Image distortion 41/41</td>
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<td></td>
<td>Micropsia 10/41</td>
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<tr>
<td></td>
<td>Macropsia 0/41</td>
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<tr>
<td>Surgical outcome</td>
<td>Macular hole closed after first operation 34</td>
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<tr>
<td></td>
<td>Macular hole closed after reoperation 8</td>
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<tr>
<td>Postoperative visual acuity study eye (ETDRS-letters)</td>
<td>Range 46–86</td>
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<tr>
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<td>Mean ± SD 68 ± 9</td>
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<tr>
<td>Postoperative visual acuity control eye (ETDRS-letters)</td>
<td>Range 69–95</td>
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<td>Mean ± SD 84 ± 5</td>
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<tr>
<td>Stage of macular hole</td>
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<tr>
<td></td>
<td>3 28</td>
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<tr>
<td>Minimum size of macular hole, μm</td>
<td>Range 199–735</td>
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<td></td>
<td>Mean ± SD 438 ± 121</td>
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<tr>
<td>Maximum size of macular hole, μm</td>
<td>Range 623–1459</td>
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<tr>
<td></td>
<td>Mean ± SD 922 ± 216</td>
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</tbody>
</table>

$n = 42$ eyes in 42 patients.

(range, 37–67 ETDRS letters; Table 1). The mean postoperative visual acuity was 68 ± 9 SD (range, 46–86 ETDRS letters).

Preoperative interocular disparity was found to decrease with increasing eccentricity ($P < 0.001$), from a mean of 0.34° closest to the fovea, at 1° eccentricity, to a plateau of 0.2° at an eccentricity of 3° to 5° (Fig. 2).

Six months after successful macular hole closure, the 42 patients demonstrated an interocular disparity that was independent of eccentricity ($P = 0.962$) and had a mean disparity below 0.1° (Fig. 2), which corresponds to a minor degree of nomial residual micropsia in the average patient. Compared to the preoperative baseline, interocular disparity at follow-up was reduced at all eccentricities ($P < 0.001$), the reduction being most prominent at smaller eccentricities ($P < 0.001$; Fig. 2).

The maximum preoperative interocular disparity was higher than 0.125° in all patients and had a mean value of 0.35° (Fig. 3). After surgery, no interocular disparity was detected in 10 eyes, the mean value for the entire study population of 42 patients being 0.13° (Fig. 3). Surgery was associated with no change in maximum disparity in four patients, all of whom had a baseline maximum disparity of 0.25 or higher (Fig. 3).

Disparity was decreased in at least one or more eccentricities in all patients. Nine patients even demonstrated negative disparities corresponding to macropsia (range, $-0.0625$ to $-0.25°$) at some eccentricities, but no patient had consistent macropsia at all eccentricities.

![FIGURE 2. Metamorphopsia before and after surgery. Mean interocular disparity in relation to reference eccentricity in 42 patients with unilateral stage 2 or 3 macular hole at baseline and 6 months after surgery. The interocular disparity level was significantly reduced at all eccentricities 6 months after surgery ($P < 0.001$). The largest changes were found in the smaller eccentricities ($P < 0.001$). Error bars, SD.](https://iovs.arvojournals.org/)

![FIGURE 3. Interocular disparity before and after surgical treatment of macular hole in 42 patients. Maximum disparity at baseline and at 6-month follow-up after successful treatment of idiopathic stage 2 or 3 macular hole in 42 patients. In 10 patients, no visuospatial distortion was detectable at the 6-month follow-up. Four patients did not show any change in maximum distortion value.](https://iovs.arvojournals.org/)
from the edge of the hole margin. Higher resolution OCT has markedly in severity and in extent, ranging from 200 to 750 photoreceptor atrophy in eyes with macular hole can vary. Anecdotally may be caused by the limited resolution of the OCT procedure used in this study. Histopathology has shown that higher resolution OCT has indeed supported these findings and has shown signs of other postoperative conditions such as disruption of multiple retinal layers, cystoid foveal spaces, and persistent foveal detachment.

Idiopathic macular hole has long been recognized as a condition associated with tangential photoreceptor displacement. Cerebral cortical plasticity is often suggested as a mechanism that could lead to a compensatory remodeling of perceptual projection of receptor units in visual space, but the strong association between interocular disparity in patients with a unilateral macular hole and subsequent reduction or elimination of disparity after macular hole closure does not support any role for cortical plasticity in compensating for the distortion induced by the deformation of the retina. Indeed, we previously found that the angular maximum interocular disparity was generally within the limits predicted by the smallest hole diameter expressed in degrees of visual angle.

In the present study, we found a roughly biphasic shape of the disparity versus eccentricity function (Fig. 2), the trend being nearly flat from 4° to 5°. This suggests that two types of photoreceptor displacement act in concert in eyes with a macular hole: tangential displacement and inner margin eversion (Fig. 5). Thus, eversion of photoreceptors along the free margin of the hole could be responsible for the steep part of the curve closest to the center of the fovea, whereas tangential photoreceptor displacement could be responsible for the flatter part of the curve corresponding to higher distances from the fovea. This hypothesis is supported by the typical finding on OCT images of a central full-thickness defect in the neuroretina surrounded by a thickened retina and an accumulation of subretinal fluid that often covers a much larger area than the hole itself. Near the margin of the hole, a portion of the detached retina often appears to have been partially everted, in the shape of a bascule bridge pivoted at the photoreceptor-RPE junction at the subretinal edge of the hole. This formation is difficult to validate by inspection of the OCT scan, because the thickening of the retina disturbs the layered architecture of the retina and induces scatter that attenuates the image of the outer aspect of the retina and because rotation of the retina must be assumed to alter its reflectivity as seen from the direction of the pupil. Nevertheless, histopathologic studies of idiopathic macular holes show that even after 3 years, intact photoreceptors can be found on the elevated rim of the hole. Furthermore, ultrahigh-resolution OCT images of idiopathic macular holes suggest that an intact band of photoreceptor outer segments is found from the subretinal rim to the inner edge of the hole.

Our data suggest that eversion of the outer retina is an essential mechanism of photoreceptor displacement and induction of metamorphopsia (Fig. 5). In addition, the finding of residual metamorphopsia that is independent of eccentricity after biomicroscopically successful surgical repair of a macular hole suggests that photoreceptor repositioning is incomplete.

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**FIGURE 4.** Prognostic value of preoperative disparity. Stratification of patients according to interocular disparity. At 1° eccentricity, patients with interocular disparity < 0.35° showed 9 more EDTRS letters improvement in final visual acuity (95% confidence interval, 14 – 4 EDTRS letters) than did patients with disparities > 0.35°.

**DISCUSSION**

The present study is the first conducted to evaluate interocular photoreceptor displacement and repositioning after macular hole surgery as a function of retinal location and visual field eccentricity. After surgery, a significant reduction in metamorphopsia was found in the population as a whole, and maximum interocular disparity in perceived stimulus size was reduced in 38 of 42 patients. Lesser degrees of preoperative interocular disparity near the margin of the macular hole were associated with a better visual outcome. In relation to retinal location, this means that the largest preoperative displacement of photoreceptors away from the center of the visual field was associated with the least successful repositioning of photoreceptors, despite biomicroscopic and tomographic hole closure.

Visuospatial distortion assessment appears to reflect aspects of vision that are of functional importance to the patient. Not only does metamorphopsia degrade vision when it affects an only seeing eye, it can also degrade binocular function in patients with a normal fellow eye.

To fully understand macular hole disease and the effect of interventions, assessment of photoreceptor structure and function should be made before and after surgery. In the present study, in 13 eyes OCT demonstrated a persistent foveolar gap in the photoreceptor layer after surgery despite, anatomic hole closure. Our data did not permit evaluation of whether this is caused by incomplete photoreceptor repositioning or loss of photoreceptors. We did not, however, find any effect on final visual acuity of the photoreceptor layer discontinuity, unlike a previous surgery study in which poor final visual acuity was related to discontinuity of the photoreceptor band on OCT after surgery, but in agreement with a study of 14 eyes in which macular holes closed spontaneously. These discrepancies may be caused by the limited resolution of the OCT procedure used in this study. Histopathology has shown that photoreceptor atrophy in eyes with macular hole can vary markedly in severity and in extent, ranging from 200 to 750 μm from the edge of the hole margin. Higher resolution OCT has indeed supported these findings and has shown signs of other postoperative conditions such as disruption of multiple retinal layers, cystoid foveal spaces, and persistent foveal detachment.

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Our data suggest that eversion of the outer retina is an essential mechanism of photoreceptor displacement and induction of metamorphopsia (Fig. 5). In addition, the finding of residual metamorphopsia that is independent of eccentricity after biomicroscopically successful surgical repair of a macular hole suggests that photoreceptor repositioning is incomplete.

**FIGURE 5.** Proposed mechanism of photoreceptor displacement and induction of metamorphopsia in eyes with macular hole by a combination of eversion and tangential centripetal movement. Arrows: direction of displacement. The thickness of the arrows indicates the magnitude of displacement. White circles indicate that the detached lip of the macular hole is everted by rotation about a pivotal junction between the photoreceptors and the RPE at the subretinal edge of the hole.
FIGURE 6. Proposed anatomic structure of the retina after biomicroscopic closure of the hole with a persistent discontinuity of the photoreceptor outer segment layer (gray box). Arrows indicate that despite elimination of eversion and reattachment of the retina, residual tangential displacement was responsible for a central defect in the photoreceptor matrix that may help explain why residual metamorphopia that was independent of eccentricity was found after successful surgery in 32 of 42 patients.

(Fig. 6). According to this theory, closure of the macular hole by elimination of eversion may be complete and sufficient to close the hole, yet residual tangential displacement may be found even after the inner layers of the hole have closed. It could be argued that the residual metamorphopia detected after surgery with our test is the result of random variation around the mean. However, 11 healthy subjects expressed a median interocular disparity of 0.0° for all but one stimulus size near the center of the visual field. In our study population, macular hole surgery was followed not only by improved visual acuity but also by a considerable reduction in disparity that is likely to be improved central scotoma after idiopathic macular hole surgery. 2002;109:2160–2164.

All patients in our study showed evidence of some degree of photoreceptor displacement in the eye with the macular hole, and patients having less than 0.35° of interocular disparity at 1° eccentricity at baseline showed higher postoperative visual acuity. This observation corroborates those in previous studies showing that a small macular hole diameter is associated with a better functional outcome. 25–24. Although macular hole and central scotoma but no evidence of photoreceptor displacement have been described in 25% of the cases in a previous study, no such patient was found in our study. Absence of detectable disparity and, hence, photoreceptor displacement, suggests the presence of full-thickness loss of a portion of the foveal retina or loss of photoreceptor function and viability near the rim of the hole. The complete absence of eyes without evidence of photoreceptor displacement in our study indicates to us that the latter mechanism is the most likely. In the present study, we found consistent visual improvement after surgery, supporting that macular hole surgery is an attractive therapeutic option independent of preoperative visual acuity and duration of symptoms, within the range represented here and in studies with similar findings.

In conclusion, we have found that metamorphopia related to photoreceptor displacement in eyes with a macular hole can be assessed objectively by using a simple test object designed specifically for this condition and expressed in degrees of interocular disparity before and after surgical treatment. Furthermore, the study showed that preoperative interocular disparity near the center of the visual field predicts final best corrected visual acuity. In our study population, macular hole surgery was followed not only by improved visual acuity but also by a considerable reduction in disparity that is likely to be of benefit for binocular visual function, visual comfort, and visual stamina when reading or performing near-vision tasks, especially those that require stereo acuity.

References