Optimal Amount of Anisometropia for Pseudophakic Monovision

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Monovision is a widely accepted optical method used to achieve visual acuity from far to near distances without spectacles. This method began primarily with the use of contact lenses for presbyopic patients, in whom one eye is optimized for far vision and the fellow eye for near. Since the early 1990s, this method has also been used for phakic patients who undergo corneal refractive surgery. More recently, monovision has been utilized for pseudophakic patients receiving monofocal intraocular lenses (IOLs) after cataract extraction.

Previous studies showed that success of monovision, based on patient satisfaction, depends on useful uncorrected binocular visual acuity from far to near, on distance correction of the dominant eye, and on minimal impairment of stereopsis and binocular contrast sensitivity. Some studies have shown that the dominant eye should be optimized for far vision and that monovision success is influenced by the magnitude of ocular dominance, although some controversy remains. In addition, Jain et al reported that unsuccessful monovision patients had approximately 50 seconds of arc reduction in stereovision than successful patients. Furthermore, Pardhan and Gilchrist reported that with more than 1.50 diopters of defocus, binocular contrast sensitivity decreased to a level worse than monocular sensitivity due to loss of binocular summation.

Many studies have shown that monovision for phakic patients with approximately 1.00 to 1.50 D of anisometropia obtained with a contact lens or after refractive surgery provides useful binocular visual acuity from far to near distances. However, it should be noted that most patients who were candidates for phakic monovision were relatively young.

ABSTRACT

PURPOSE: To determine the optimal target anisometropia for pseudophakic monovision.

METHODS: Thirty-five bilaterally pseudophakic patients who received monofocal intraocular lenses were included in the study. Binocular corrected distance visual acuity (CDVA) and binocular distance-corrected near visual acuity (DCNVA) and stereoacuity were measured after simulating 1.00, 1.50, and 2.00 diopters (D) of monovision by adding the appropriate spherical lens to the nondominant eye. We presumed that mean binocular DCNVA of 20/40, binocular CDVA of 20/25, and stereoacuity <100 seconds of arc (arc sec) were necessary for successful monovision.

RESULTS: With no anisometropia, mean binocular DCNVA was 20/97, binocular CDVA was 20/20, and mean stereoacuity was 71 arc sec. With 1.00 D of monovision, mean binocular DCNVA was only 20/60, although binocular CDVA and mean stereoacuity were sufficient. With 1.50 D of monovision, binocular DCNVA was 20/38, binocular CDVA at other distances exceeded 20/21, and stereoacuity was 100 arc sec, which was a 29-arc sec reduction. With 2.00 D of monovision, binocular DCNVA reached 20/31, but stereoacuity was 158 arc sec, which was an 87-arc sec reduction. The number of patients who met the criteria for successful monovision was significantly greater with 1.50 D of monovision than with 1.00 or 2.00 D of monovision (P=.0134).

CONCLUSIONS: Pseudophakic monovision with anisometropia of 1.50 or 2.00 D provides useful binocular visual acuity from far to near. However, because stereopsis with 2.00 D of monovision is substantially impaired, approximately 1.50 D of anisometropia is thought to be optimal for successful monovision. [J Refract Surg. 2011;27(5):332-338.] doi:10.3928/1081597X-20100817-01
(40 to 50 years), and thus likely to have some degree of ocular accommodation. Accordingly, in pseudophakic patients who have no ocular accommodation, visual acuity outcome may be worse than in phakic patients. Furthermore, optimal target anisometropia for pseudophakic monovision may be different from that for phakic monovision.

The purpose of this study was to examine optimal target anisometropia for pseudophakic monovision after cataract surgery. Although useful binocular visual acuity at far to near distances is essential for the success of this method, less impairment of stereopsis is also important. Accordingly, all-distance visual acuity and stereoacuity were examined after simulation of various degrees of anisometropia.

**PATIENTS AND METHODS**

**Patients**
All consecutive patients scheduled to undergo bilateral cataract extraction and implantation of a monofocal IOL between July and September 2009 were screened for recruitment by a clinical research coordinator. Exclusion criteria were severe pathology of the optic nerve, macula, or cornea; opaque media other than cataract; history of ocular inflammation or surgery; abnormal ocular position; irregularly shaped pupil; corneal astigmatism >1.50 D; and anticipated difficulty with examination or follow-up. Screening was continued until 35 patients were recruited. The institutional review board approved the protocol, and informed consent was obtained from each patient.

**Surgical Procedure**
One ophthalmologist (K.H.) performed all surgeries using almost the same procedure as described previously. First, a continuous curvilinear capsulorhexis was accomplished using a bent needle. Next, a 2.5-mm clear corneal incision was made, and phacoemulsification was accomplished using a hydrophobic acrylic IOL (SA60AT; Alcon Laboratories Inc, Ft Worth, Texas) was placed into the capsular bag using the Monarch II injector (Alcon Laboratories Inc).

**Simulation of Monovision**
Simulation of pseudophakic monovision with 1.00, 1.50, and 2.00 D of anisometropia was performed approximately 1 month after surgery on the second operated eye. The dominant eye was determined using a hole-in-card test (sighting dominance) in which the patients were asked to look at a Landolt target at 5 m through a 1-cm hole in the center of the cardboard. After distance correction in both eyes, a spherical lens of +1.00, +1.50, or +2.00 D was added to the nondominant eye.

**Main Outcome Measures**
After simulation of 1.00, 1.50, and 2.00 D of monovision, binocular and monocular corrected distance visual acuity (CDVA) and distance-corrected near visual acuity (DCNVA) were measured using the all-distance vision tester (AS-15; Kowa Company Ltd, Nagoya, Japan). This device measures equivalent visual acuity from far to near distances by placement of a spherical lens and various sized visual targets at appropriate distances along the visual axis. For example, the visual acuity at ∞ m is measured by placing a spherical lens (focal distance=250 mm) 250 mm from the patient’s eye and a visual target at 500 mm.

Near stereoacuity at 0.4 m was examined using the Titmus stereo test under photopic condition (80 to 100 cd/m²). Stereoacuity was determined by the number of circles that a patient answered correctly and this number was converted to seconds of arc (arc sec) for statistical analysis. The stereoacuity level of circle 5, which is equivalent to 100 arc sec is considered to be the lowest limit of useful stereoacuity. The reduction in stereoacuity was calculated by subtracting the values at 1.00, 1.50, and 2.00 D of anisometropia from that at 0.0 D of anisometropia (baseline).

The subjective refractive status (spherical and cylindrical powers) and keratometric cylinder were measured using an autorefractometer (KR-7100; Topcon, Tokyo, Japan). The manifest spherical equivalent was determined as the spherical power plus half the cylindrical power. The pupillary diameter was examined using the Colvard pupillometer (Oasis Medical, Glendora, California). All examinations were performed by ophthalmic technicians who were unaware of the objectives of this study.

**Data Analysis**
Decimal visual acuity was converted to the logMAR scale for statistical analyses. Differences in mean visual acuity at far to near distances, mean stereoacuity as well as reduction in stereoacuity from baseline, and other continuous variables among groups with 1.00, 1.50, and 2.00 D of monovision were compared using the Kruskal-Wallis test. Categorical variables were compared among the three groups using the goodness of fit for chi square. When a statistically significant difference was found among the three groups, the
difference between two groups was further compared using the Mann-Whitney U test or the chi-square test with the Bonferroni adjustment. Differences with a $P$ value $<.05$ were considered statistically significant.

RESULTS

The 35 enrolled patients (12 men and 23 women) completed all scheduled examinations. Mean patient age was $68.1\pm6.9$ years (range: 55 to 80 years). Patient characteristics of the dominant and nondominant eyes are shown in Table 1. No statistically significant differences were found between dominant and nondominant eyes in CDVA, manifest spherical equivalent, keratometric cylinder, or pupillary diameter.

Mean monocular CDVA to near distances in the dominant and nondominant eye is shown in Figure 1. Mean monocular CDVA in the nondominant eye changed significantly at all distances according to the diopter of the added spherical lenses ($P=0.001$). Specifically, at distances of $\infty$, 5.0, 3.0, and 2.0 m, monocular CDVA decreased in proportion to the diopter of the added spherical lens. At 1.0 m, monocular CDVA with a 1.00-D spherical lens was best, whereas with a 1.50-D spherical lens, 0.7 m was best. At 0.5 and 0.3 m, monocular CDVA increased in proportion to the diopter of the added spherical lens.

TABLE 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Dominant Eye</th>
<th>Nondominant Eye</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (range) (y)</td>
<td>$68.1\pm6.9$ (55 to 80)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>12/23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual acuity (logMAR)</td>
<td>$-0.03\pm0.04$ (−0.08 to 0.05)</td>
<td>$-0.02\pm0.04$ (−0.08 to 0.05)</td>
<td>.7422</td>
</tr>
<tr>
<td>Snellen equivalent</td>
<td>20/19 (20/22 to 20/17)</td>
<td>20/19 (20/22 to 20/17)</td>
<td></td>
</tr>
<tr>
<td>Spherical equivalent (D)</td>
<td>$-0.73\pm0.83$ (−3.50 to 0.125)</td>
<td>$-0.64\pm0.81$ (−4.00 to 0)</td>
<td>.3596</td>
</tr>
<tr>
<td>Keratometric cylinder (D)</td>
<td>$0.74\pm0.36$ (0 to 1.50)</td>
<td>$0.60\pm0.13$ (0 to 1.50)</td>
<td>.0896</td>
</tr>
<tr>
<td>Pupillary diameter* (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Far</td>
<td>$3.41\pm0.71$ (2.5 to 4.0)</td>
<td>$3.43\pm0.73$ (2.0 to 6.0)</td>
<td>.9122</td>
</tr>
<tr>
<td>Near</td>
<td>$3.04\pm0.62$ (2.0 to 3.5)</td>
<td>$3.03\pm0.63$ (2.0 to 5.0)</td>
<td>.9813</td>
</tr>
</tbody>
</table>

logMAR = logarithm of minimum angle of resolution

*Pupillary diameter at far and near distances.

Note. Values represented as mean±standard deviation (range).

Figure 1. Mean±standard deviation monocular corrected distance visual acuity (CDVA) to near distances in nondominant (continuous line) and dominant eyes (dashed line). Mean monocular CDVA in the nondominant eye changed significantly at all distances according to the diopter (D) of the added spherical lens. At $\infty$, 5.0, 3.0, and 2.0 m, monocular CDVA decreased in proportion to diopter of added spherical lens. At 1.0 m, monocular CDVA with 1.00 D of spherical lens was best, whereas with 1.50-D spherical lens, 0.7 m was best. At 0.5 and 0.3 m, monocular CDVA increased in proportion to the diopter of the added spherical lens.
lar CDVA increased in proportion to the diopter of the added spherical lens.

At distances of $\approx$, 5.0, 3.0, 2.0, and 1.0 m, mean binocular CDVA did not differ significantly among groups with 1.00, 1.50, and 2.00 D of monovision (Fig 2). However, at 0.7, 0.5, and 0.3 m, there were statistically significant differences among the three groups ($P<.0044$). When comparing two groups, mean binocular CDVA at 0.7 m was significantly better in the 1.50-D monovision group than in the 2.00-D monovision group ($P=.0015$).

At 0.5 m, binocular CDVA in the 1.50-D monovision group was significantly better than in the 1.00-D monovision group ($P<.0001$) and did not differ significantly from the 2.00-D monovision group. At 0.3 m, binocular CDVA was best in the 2.00-D monovision group, followed by the 1.50-D monovision group and the 1.00-D monovision group. The difference was not significant between the 1.50-D and 2.00-D groups.

Mean stereoacuity with no anisometropia (baseline) was 71 ± 34 arc sec, but mean stereoacuity (Fig 3) and re-
duction in stereoacuity (Fig 4) worsened significantly in proportion to the degree of anisometropia ($P=0.0014$ in stereoacuity and $P<0.0001$ in reduction). When comparing two groups, mean stereoacuity in the 2.00-D monovision group was significantly worse than in the 1.00- or 1.50-D monovision groups ($P=0.0143$). Furthermore, reduction in stereoacuity in the 2.00-D monovision group was significantly greater than in the 1.00- or 1.50-D monovision group ($P=0.0004$).

In this study, we assumed binocular DCNVA of 20/40, binocular CDVA of 20/25, and stereoacuity $<100$ arc sec to be necessary for successful monovision. Mean values in only the 1.50-D monovision group met these criteria. Furthermore, the number of patients who met these criteria was significantly greater in the 1.50-D monovision group than in the 1.00- or 2.00-D monovision group ($P=0.0134$) (Table 2).

**DISCUSSION**

Our study demonstrated that binocular CDVA to intermediate distances up to 1.0 m was useful or better than 20/22 in all three groups (1.00, 1.50, and 2.00 D of monovision) and did not differ significantly among these groups. However, distances of 0.7, 0.5, and 0.3 m were significantly different among groups. More specifically, when comparing two groups for intermediate vision at 0.7 and 0.5 m, mean binocular CDVA with 1.50 D of monovision was 20/20 and exceeded 20/23 with 2.00-D monovision, both of which were better than with 1.00-D monovision. For near vision at 0.3 m, binocular CDVA with 1.50 and 2.00 D of monovision provided useful visual acuity with a mean of 20/40, but mean CDVA with 1.00-D monovision was only 20/60. These results indicate that pseudophakic monovision with 1.50 and 2.00 D of anisometropia provide useful binocular visual acuity from far to near distances but that binocular near visual acuity was not sufficient with 1.00 D of monovision.

In contrast, mean stereoacuity in eyes with 1.00 and 1.50 D of monovision reached 100 arc sec, which is considered to be the lowest limit of useful stereovision. However, mean stereoacuity in eyes with 2.00 D of monovision deteriorated by 158 arc sec. Furthermore, mean reduction in stereoacuity was 16 arc sec with 1.00-D monovision and 29 arc sec with 1.50-D monovision, but was 87 arc sec with 2.00-D monovision; therefore, the difference was 58 arc sec between 1.50 and 2.00 D of monovision. It has been shown that unsuccessful monovision patients had a $>50$-arc sec reduction in stereoacuity than successful patients. A previous study by Greenbaum showed that subjective patient acceptance was 90% with 2.75 D of pseudophakic monovision. However, our objective results suggest that stereopsis with $\geq 2.00$ D of monovision is substantially worse and may lead to failure of the monovision.

In this study, we assumed binocular DCNVA of 20/40, binocular CDVA of 20/25, and stereoacuity $<100$ arc sec to be necessary for successful monovision, yet mean values of these parameters met the above criteria in only those patients with 1.50 D of monovision. Furthermore, the number of patients who met these criteria was significantly greater in those with 1.50-D monovision than in those with 1.00- or 2.00-D
monovision. Based on the results of all-distance visual acuity and stereoacuity, we believe that approximately 1.50 D of anisometropia is optimal for target refraction of pseudophakic monovision.

Previous studies showed that monovision for phakic patients, either those using a contact lens or after corneal refractive surgery, provide useful visual acuity from far to near distances with mean anisometropia being between 1.00 and 1.50 D in those studies.2,4,5,8 Durrie24 claimed that 1.50-D add power in a nondominant eye provides best near and intermediate vision for contact lens monovision. Although a decrease in stereoacuity and binocular contrast sensitivity were evident, patient satisfaction of phakic monovision was generally high.2,4,5,8 On the other hand, mean anisometropia was >2.00 D, possibly because a greater degree of anisometropia was necessary to provide useful near vision as there was no ocular accommodation. For instance, Ito and Shimizu12 reported that reading ability in patients with approximately 2.00 D of pseudophakic monovision was better than in patients who received refractive multifocal IOLs in both eyes. However, our previous study showed that postoperative anisometropia is the major predictor of impaired stereopsis, and that stereoacuity worsens markedly when anisometropia is >1.50 D.25 Furthermore, it has been shown that with >1.50 D of defocus, binocular contrast sensitivity decreases to a level even worse than monocular sensitivity.20 Thus, when anisometropia exceeds 1.50 D, binocular function may deteriorate to a critical level in most pseudophakic patients.

A limitation of our study is that neither binocular contrast sensitivity nor ocular position (esophoria or exophoria) was examined, principally because the patients, all of whom were volunteers, would have to expend too much effort for the examinations. However, a previous study showed that binocular contrast sensitivity worsens critically when >1.50 D of anisometropia is present, which is due to a loss of binocular summation.20 In addition, it has been shown that the clinical significance of esophoric or exophoric shift may be negligible because the magnitude of the deviation is not great.4

Pseudophakic monovision with anisometropia of 1.50 or 2.00 D induced by multifocal IOLs provides useful binocular visual acuity from far to near distances. However, because stereopsis is impaired critically with 2.00 D of monovision, approximately 1.50 D of anisometropia is thought to be optimal for successful pseudophakic monovision. As an alternative option to monovision created by multifocal IOLs, new generation multifocal IOLs are now available that can provide useful far and near visual acuity.26-29 However, intermediate visual acuity is insufficient in most of these multifocal IOLs because the focal points are limited to far and near. More recently, several types of multifocal IOLs with low addition power have been developed to provide sufficient intermediate visual acuity.22,30 Accordingly, we believe that pseudophakic monovision due to implantation of multifocal IOLs of different add powers in fellow eyes may be of benefit in achieving useful all-distance vision without compromising binocular function. Further study is required to examine the binocular visual function in patients who receive multifocal IOLs of different add powers in fellow eyes.

**AUTHOR CONTRIBUTIONS**

Study concept and design (K.H.); data collection (K.H., M.Y., S.M.); analysis and interpretation of data (K.H., H.H.); drafting of the manuscript (K.H.); critical revision of the manuscript (M.Y., S.M., H.H.); statistical expertise (K.H.)

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