Original Article

Stereoacuity after Wavefront-guided Photorefractive Keratectomy in Anisometropia

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Abstract

Purpose: To determine changes in stereoacuity in anisometropic myopic eyes after photorefractive keratectomy (PRK).

Methods: Myopic patients with at least 1 diopter (D) of anisometropia in sphere, astigmatism, or spherical equivalent who were referred to our hospital for excimer refractive surgery were enrolled as a prospective sequential interventional case series. All patients underwent wavefront-guided photorefractive keratectomy (WFG-PRK) using the Technolas Perfect Vision (217z) Excimer laser machine. Changes in binocular stereoacuity were evaluated using the TNO and Butterfly stereoacuity tests before and at 2 weeks, 1 month, and 3 months after the operation.

Results: Between January and November 2015, a total of 98 eyes of 49 patients (71.4% men) with a mean age of 28 ± 5.5 years, mean myopia of −3.32 ± 1.74 D, and mean astigmatism of 1.3 ± 1.3 D were enrolled in this study. Preoperative mean stereoacuity values were 102 ± 103.44 and 56.8 ± 41 seconds of arc (s/arc)as measured by the TNO and Butterfly stereoacuity tests. Mean stereoacuity improved to 90 ± 110.52 s/arc ($P = 0.009$) and 56.5 ± 41.3 s/arc ($P = 0.80$), respectively, 6 months after WFG-PRK. Overall improvement in stereoacuity was 10.2% and 6.12% according to the TNO and Butterfly stereoacuity tests, respectively.

Conclusion: Stereoacuity improves after WFG-PRK for treatment of anisometropic myopia. This improvement is more accurately detectable by the TNO than the Butterfly stereoacuity test.

Keywords: Anisometropia; Photorefractice Keratectomy; Stereoacuity; Wavefront-guided

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INTRODUCTION

Visual fusion is the integration of two separate images in the retina of two eyes and is necessary for perception as a unified image in the brain. This process is possible due to stimulation of conjugate areas in the retinas of both

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eyes. The similarity of image shape and size perceived by two eyes is mandatory for a successful sensory fusion.[1]

Fusion can be classified into sensory, motor, and stereopsis types; the last is regarded as the highest order of fusion. Stereopsis is defined as the binocular perception of relative depth as a result of horizontal retinal image disparity.[2] Anisometropia is defined as a difference of at least one diopter (D) or more in refractive error in 1 or all meridians between the two eyes. Uncorrected anisometropia may cause an irreversible impairment in visual development, to the extent that a condition known as anisometropic amblyopia may result.

Anisometropia is regarded as a major cause of amblyopia in the pediatric ophthalmic literature.[3,4] Anisometropia should be corrected appropriately at any age to improve binocular vision and enhancement of stereopsis.[5-8] Even corrected anisometropia can be a cause for fusion impairment, asthenopia, headache, and photophobia due to the differences in image size and induced prismatic effects.[9-11]

Danders first introduced aniseikonia as a result of uncorrected anisometropia. He believed that this refractive difference could result in abnormalities of binocular vision.[12] Even mild anisometropia may become associated with impairment of binocular function and stereopsis in adults.[13-15]

Three-dimensional (3D) perception of the environment, depth perception, and stereopsis are some of the highest developments in human visual function. A difference of more than 5 percent in image size is considered to be incompatible with binocular fusion, so aniseikonia will ultimately reduce depth perception.[16]

Anisometropia and aniseikonia may become symptomatic following correction of the conditions by glasses. Changing the design of spectacle lenses or prescribing iseikonic glasses have been proposed as a solution.[17] A second option is to correct anisometropia using contact lenses that reduce the difference in image size and subsequently eliminate the prismatic effect induced by glasses. However, contact lenses are generally intolerable by children.[18,19] Another potential method for elimination of anisometropia and subsequent management of aniseikonia is refractive surgery using an excimer laser.[16]

The purpose of this study was to evaluate the effect of correction of anisometropia and subsequent aniseikonia by wavefront-guided photorefractive keratectomy (WFG-PRK) on depth perception and stereoacuity.

METHODS

The present study was performed as a before –after treatment between January and November 2015. A total of 49 patients underwent WFG-PRK for correction of myopia or myopic astigmatism. Sampling was not randomized and was based on a sequential patient referral.

Inclusion criteria for this study were patients who were voluntary candidates for refractive surgery; were aged 18 to 40 years; and had refractive myopia in the range of 1 to 7 D, astigmatism between –0.5 and 5.0 D, minimum best corrected visual acuity (BCVA) of 20/40 in one eye, no history of previous ocular surgery, absence of any systemic disorder, and absence of any obvious ocular deviation. Patients must have anisometropia of 1 D or more in one or all meridians (spherical, spherical equivalent (SE), or astigmatism) to be included in the study. Patients with known contraindication for corneal refractive surgery, suffering from systemic diseases such as diabetes or autoimmune disorders, patients with one eye, and patients with a residual refractive error of more than 0.75 D six months after surgery were excluded from the study.

The study proposal was approved by the Ethical Committee of the Ophthalmic Research Center and it was conformed to the tenets of the Declaration of Helsinki.

Patients eligible for the study underwent comprehensive preoperative examinations including refraction determination (manifest and cycloplegic) of best corrected distant visual acuity (CDVA) with a digital chart projector (CP-770, Nidek, Kamagori, Japan) objective near phoria measurement with prism bar, slit lamp biomicroscopy, Goldmann applanation tonometry, and indirect fundoscopy. The stereoacuity measurement was performed using two methods: the TNO test (Ootech, AG Veeneldaal, Nedherlands) and Butterfly stereoacuity tests (BFSA; Stereo Optical, Chicago, USA). Stereoacuity measurements were performed by an experienced optometrist before and 6 months after surgery, and the results were compared.

The BFSA test consists of two vectographic displays with Random-Dot Stereogram (RDS) patterns and a pair of polarized filters. During this test, refractive error was corrected by glasses, and then test pages were placed 40 cm in front of the patient. Illumination was kept constant during the test. After wearing polarizing glasses, patients were asked to point to bolded circles inside each rectangle, representing a distinct degree of stereoacuity; depth perception of 40-80 s/arc was considered "good," 80–200 s/arc was "moderate," and 200–800 s/arc was "poor."

Measurement by the TNO test is based on the anaglyph principle and RDS patterns. During this test, the patient's refractive error was corrected, and then TNO red and green filters were placed before his/her eyes. Pages of this test contain circles with a cut edge; each circle represents a pre-defined degree of stereoacuity. During the test, the patients were asked to identify the cut border of each circle. The quality of stereopsis measured by TNO was classified into three categories: 15-60 s/arc was considered "good," 60-240 s/arc was "moderate," and 240-480 s/arc was "poor."

After obtaining informed consent, patients underwent WFG-PRK using the standard technique, which was described previously.[20]

Preoperative wavefront evaluation was performed using a Zywave II (Technolas Perfect Vision, Bausch & Lomb, Inc., Bridgewater, NJ, USA) for a 6-mm pupil size. All operations were performed by a single surgeon using a Technolas 217z (Technolas Perfect Vision, Bausch & Lomb, Inc.) under topical anesthesia.

After the complete closure of epithelial defects (3-5 days), the bandage contact lens was removed. After 2 weeks of betamethasone 0.1% and ciprofloxacin 0.3% 4 times per day, fluorometholone 0.1% was substituted, continued, and then tapered to discontinue in 3 months. Follow-up examinations were repeated at 1, 3, and 6 months after surgery.

The efficacy index was calculated as the ratio of the postoperative uncorrected distant visual acuity (UDVA) to the preoperative CDVA, whereas the safety index was calculated as the ratio of the postoperative CDVA to the preoperative CDVA.

For data analysis, statistical analysis was performed using SPSS v. 21 (IBM Inc., Chicago, USA) and quantitative data normalization was determined using the Kolmogorov-Smirnov (S-K) test. The paired *t*-test was used for paired data analysis. The Wilcoxon test was used for nonparametric data analysis. *P* values <0.05 were considered significant.

RESULTS

This study was conducted between January and November 2015 and included 49 myopic or myopic astigmatism patients with more than 1 D of spherical, SE, or astigmatic anisometropia [Tables 1-3].

Men comprised 71.4% of patients. Mean age was 27.5 years (for men) and 27.9 years (for women), respectively; there was no statistical difference in age ($P < 0.001$). The mean value for refractive error was −3.32 D (−1 to −6.5 D) for myopia, −4.37 D (−1.75 to −7.75 D) for SE, and 1.3 D (−0.75 to −5.0 D) for astigmatism.

The average preoperative CDVA was + 0.12 LogMAR (20/27); uncorrected distant visual acuity (UDVA) was + 0.09 LogMAR (20/23). The overall efficacy and safety indices were 1.08 ± 0.34 and 1.05 ± 0.2, respectively.

The mean value of stereoacuity according to the BFSA test was 56.8 ± 41 s/arc before and 56.5 ± 56 s/arc after WFG-PRK. This difference was not statistically significant. By the TNO test, the preoperative mean of stereoacuity improved from 102 ± 103.44 s/arc to 90 ± 110.52 s/arc after surgery. This difference was statistically significant ($P < 0.009$).

The results of stereoacuity determined by the BFSA and TNO methods before and after WFG-PRK are presented in Tables 4 and 5. Surgery had no effect when measured by BFSA in the group with good preoperative depth perception. Depth perception was improved after surgery in 3 patients (37%) in the

Table 1. Anisometropia classification based on spherical power (diopters)

Anisometropia (D)	Number	Percentage
1	30	61.2
1-2	13	26.5
>2	6	12.2
Total	49	100

D, diopter

Table 2. Anisometropia classification based on the cylinder power (diopters)

Anisometropia (D)	Number	Percentage
1	34	69.4
1-2	9	18.4
>2	6	12.2
Total	49	100

D, diopter

Table 3. Anisometropia classification based on the spherical equivalent (diopters)

Anisometropia (D)	Number	Percentage
1	23	46.9
1-2	18	36.7
>2	8	16.3
Total	49	100

D, diopter

Table 4. Number of patients and percentage of level of stereoacuity (sec/arc) measured by the BFSA test before and after *WFG-PRK* in myopic anisometropia

BFSA	Poor (200-800)	Moderate (80-200)	Good (40-80)
Pre-op	0 (0)	8 (16.3%)	41 (83.7%)
Post-op	0 (0)	5 (10.2%)	44 (89.8%)

BFSA: Butterfly stereoacuity test; Pre-op, preoperative; Post-op, postoperative; WFG-PRK, wavefront-guided photorefractive keratectomy

Table 5. Number of patients and percentage of level of stereoacuity (sec/arc) measured by the TNO test before and after WFG-PRK in myopic anisometropia

TNO	Poor (240-480)	Moderate (60-240)	Good (15-60)
*Pre-op	3 (6.12%)	15 (30.6%)	31 (63.2%)
†Post-op	3 (6.12%)	10 (20.4%)	36 (73.4%)

*Pre-op, preoperative; †Post-op, postoperative; WFG-PRK, wavefront-guided photorefractive keratectomy

group with moderate stereoacuity before surgery. No improvement in depth perception was encountered in the group with poor stereoacuity before surgery. The ratio of overall improvement using the BFSA test was 6.12% [Table 4].

Comparison of pre- and post-operative stereoacuity measurements using the TNO test is presented in Table 5. In patients classified as having good and poor

stereopsis, no improvement occurred after surgery. However, stereoacuity improved in five patients with moderate pre-operative depth perception. As a result, the percentage of patients with good acuity before surgery was the same according to the TNO (33.3%) and BFSA (37.5%) methods; the difference was not statistically significant ($P = 0.001$). In patients with poor preoperative stereoacuity, there was no improvement after WFG-PRK.

DISCUSSION

Today, different techniques of refractive surgery are becoming popular for correction of refractive errors. Refractive surgery eliminates ametropia, reduces levels of anisometropia between eyes, balances aniseikonia, and theoretically improves binocular vision and stereopsis.

Stereopsis and stereoacuity are not commonly evaluated before and after refractive surgery, as the usual criteria for the success of such surgeries are vision status of each eye. The current study was designed to evaluate the effect of WFG-PRK on the reduction of anisometropia. Subsequent postoperative effects on binocular function and stereoacuity were assessed using the TNO and BFSA methods.

The mean spherical equivalent of corrected refractive error in the Kirwan study was −3.6 ± 1.7 D,[21] and Ghanem reported a value of −7.75 ± 2.25 D.[22]

It has been shown that correction of more than 7 D of myopia by excimer laser surface ablation may result in reduced corneal clarity, inducing blurred vision and subsequent reduction in stereoacuity. In the current study, the range of corrected myopia was limited to -7 D to control this confounding effect. The overall follow-up time in most previous studies was 3 months, which corresponds to stabilization of vision after refractive surgery.[23] After this time, the stability of vision is suitable for evaluation of binocular functions. Therefore, the final evaluation of depth perception in the current study was planned for 6 months after surgery.

Anisometropia is one of the major refractive conditions affecting binocularity. Even a mild degree of anisometropia may cause significant impairment of binocular function in adults. Book et al studied binocular dysfunctions in patients with optically induced anisometropia.[15] Binocular functions were evaluated by the Titmus test while fusional abilities were assessed using the Worth Four Dot and Bagolini tests. They showed that stereoacuity was impaired by induced anisometropia. One diopter of spherical anisometropia reduced stereoacuity by 85-87 s/arc, and one diopter of cylindrical anisometropia reduced it by 55 s/arc. Even a small degree of anisometropia was associated with a considerable reduction in depth perception. A proposed explanation for this observation was foveal suppression.[15]

Sjostrad et al stated that anisometropic amblyopic eyes lack binocularity, central fusion, and an acceptable level of stereoacuity. Therefore, LASIK maybe an effective and safe method for reducing anisometropia in these patients.[23] The effectiveness and safety of WFG-PRK have been determined to be comparable to LASIK.[22] In this study, the effectiveness and safety of the procedure were also evaluated and demonstrated through the corresponding indices. Appropriate effectiveness and safety indices are considered to be greater than 1.0.[22]

Astle reported that LASIK was an effective method for treatment of anisometropia in children.[24] Kirwan et al investigated postoperative stereoacuity after monocular and binocular myopic refractive surgery.[21] They enrolled 83 patients including55 bilateral and 28 unilateral cases using the Technolas 217z excimer machine. The anaglyph red-green test at a distance of 42 cm was used to measure stereoacuity. The cover-uncover test was conducted near and at a distance as a subjective test to measure fusional ability. Patients had no history of strabismus surgery. Before surgery, average stereoacuity was measured as 50 s/arc and BCVA was 20/20. After refractive surgery, 38.6% of patients demonstrated stereoacuity of 28-41 s/arc despite 0.625-4.37 D of anisometropia; 28.9% of patients achieved stereoacuity of 66-526 s/arc with 2.90 ± 1.09 D of anisometropia. They demonstrated a direct relationship between anisometropia and stereoacuity ($P < 0.005$), and its evaluation should be considered before refractive surgery.[24]

Razmju et al also investigated stereoacuity after LASIK. They evaluated stereoacuity in 200 patients using the random dot stereoacuity test before and 3 months after surgery; stereoacuity was reduced in 9.5%, increased in 32.5%, and remained unchanged in 58% of cases ($P < 0.007$). The lowest level of stereoacuity was observed in anisometropic patients. They concluded that improvement of stereoacuitymight be higher in anisometropic patients without amblyopia.[25] Pre- and postoperative vision range were not well-defined in their study, and random dot stereoacuity test is less accurate than the BFSA or TNO tests for evaluation of stereopsis. These differences may explain different results and conclusions in comparison to the current study. A recent study by Jabbarvand et al showed that improvement in stereoacuity was significantly higher in the severe anisometropic group, and the lowest improvement was in the group without anisometropia.[26] The random dot test was also applied in their study, which is less accurate in comparison to those used in the current study. However, Zarei-Ghanavati et al showed deterioration of stereoacuity after PRK.[27]

The current study included 49 anisometropic patients. In Paysse et al[28] and Razmjoo et al studies,[25] 11 patients were anisometropic and in the study by Zarei-Ghanavati et al,[27] 48 eyes were evaluated. In comparison to previous studies, enrollment of 49 patients in the present study seems sufficient for appropriate conclusions.

Kirwan et al used the anaglyph red-green test performed at a distance of 42 cm.[22] Razmjoo et al employed the random dot stereoacuity test, and Zarei-Ghanavati[27] used TNO. BFSA and TNO tests were employed in the current study for stereoacuity measurements. Patients were qualitatively classified according to BFSA and TNO depth perception results. The BFSA test is simpler due to the presence of monocular clues and local assessment of depth perception. The TNO test is designed based on RDS to measure stereoacuity more globally; therefore, it is more accurate. Employment of both methods in this study provided more accuracy in measurement of stereopsis.

Results of the current study are less comparable to previous ones due to the difference in refractive surgery techniques (LASIK vs. WFG-PRK), stereoacuity measurement tests used (BFSA and TNO), classification of levels of stereopsis by different tests (good, moderate, and poor), and duration of follow-ups. This study shows if there is preoperative moderate stereopsis in cases of anisometropic myopia (with or without) astigmatism, WFG-PRK may reduce anisometropia and improve in-depth perception and stereopsis.

In conclusion, according to the TNO and BFSA tests, mean stereoacuity was improved in anisometropic myopic patients after WFG-PRK, especially in patients with moderate stereopsis. The TNO test is superior to the BFSA test for assessment and detection of changes in stereoacuity.

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Conflicts of Interest

There are no conflicts of interest.

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