Three-Month Outcomes of Laser Vision Correction for Myopia and Hyperopia in Adults With Amblyopia

Xi Liu, MD; Steven C. Schallhorn, MD; Stephen J. Hannan, OD; David Teenan, MD; Julie M. Schallhorn, MD

ABSTRACT

PURPOSE: To evaluate the visual outcomes of laser vision correction in adults with myopic and hyperopic amblyopia.

METHODS: The medical records of patients diagnosed as having amblyopia who underwent laser refractive surgery between February 2013 and October 2017 were retrospectively reviewed. Eyes with amblyopia were analyzed, and the non-amblyopic fellow eyes of the patients who underwent laser vision correction were used as controls. The uncorrected distance visual acuity (UDVA), subjective manifest refraction, and corrected distance visual acuity (CDVA) were analyzed at the 3-month postoperative time point.

RESULTS: This study included 323 eyes of 164 patients. All patients underwent laser in situ keratomileusis (90.1%, 291 eyes) or photorefractive keratectomy (9.9%, 32 eyes). Three months postoperatively, the manifest spherical equivalent was -0.07 ± 0.55 diopters (D) (range: -1.75 to +1.30 D) and -0.10 ± 0.54 D (range: -2.13 to +1.30 D) in the amblyopia group and fellow eye group, respectively. The percentage of eyes achieving UDVA of 20/20 or better was 16.9% (15 eyes) in the amblyopia group and 61.9% (52 eyes) in the fellow eye group. The percentage of eyes that gained two or more lines of CDVA was 27.9% (24 eyes) in the amblyopia group and 6.2% (5 eyes) in the fellow eye group ($P < .01$). In the amblyopia group, there was no statistically significant difference in the mean manifest spherical equivalent between the myopic eyes and hyperopic eyes at any follow-up visit ($P = .87$, 1 month postoperatively; $P = .68$, 3 months postoperatively).

CONCLUSIONS: Laser vision correction was found to be effective and safe in adult patients with amblyopia.

[*J Refract Surg*. 2020;36(8):511-519.]

Amblyopia is a significant cause of unilateral visual impairment, in some areas accounting for 33% of all unilateral visual impairment in adult patients.[1] Traditional treatments for amblyopia include correcting the refractive error in children with spectacles or contact lenses and occlusion of the dominant eye. These treatments are based on "forcing the brain to use the amblyopic eye" by depriving the non-amblyopic eye through occlusion treatment, chemical penalization (eg, administration of atropine to temporarily disrupt accommodation), or correction of significant refractive error with spectacle wear.[2]

Although the critical visual developmental period is thought to happen in early childhood, amblyopic treatments have been shown to be effective past this time point.[3-6] Studies by the Pediatric Eye Disease Investigator Group (PEDIG) show that, in certain cases, amblyopia can be treated up to the age of 14 years.[7]

From the Department of Ophthalmology (XL, SCS, JMS) and Francis I. Proctor Foundation (JMS), University of California, San Francisco, California; the Department of Ophthalmology, Southwest Hospital, Southwest Eye Hospital, Army Medical University, Chongqing, People's Republic of China (XL); Key Lab of Visual Damage and Regeneration & Restoration of Chongqing, Chongqing, People's Republic of China (XL); Carl Zeiss Meditec, Dublin, California (SCS); and Optical Express, Glasgow, United Kingdom (SJH, DT).

Submitted: September 19, 2019; Accepted: June 12, 2020

Supported in part by NEI P30 EY002162 Core Grant for Vision Research, and by an unrestricted grant from Research to Prevent Blindness, New York, New York.

Dr. Steven Schallhorn is Chief Medical Officer of Carl Zeiss Meditec and Chairman of the Medical Advisory Board for Optical Express. Dr. Julie Schallhorn is a consultant for Carl Zeiss Meditec and Vanda Pharmaceuticals. Drs. Hannan and Teenan are employees of Optical Express. The remaining author has no financial or proprietary interest in the materials presented herein.

Correspondence: Julie M. Schallhorn, MD, 10 Koret Way K323, San Francisco, CA 94143. Email: Julie.schallhorn@ucsf.edu

doi:10.3928/1081597X-20200612-02

Moreover, a few studies report a significant improvement in visual acuity after corneal refractive surgery[3,6,8] or angle-supported phakic intraocular lens and Implantable Collamer Lens (Visian) placement in adult patients with refractive amblyopia.[9-11] Several studies have reported on the effectiveness, safety, and predictability of laser vision correction in adults with amblyopia.[3-6,12] However, these studies are limited in number or did not include a control group.

The aim of the current study was to evaluate the visual and refractive outcomes, stability, and accuracy of refractive correction in a large cohort of adults with amblyopia, including myopia and hyperopia. Visual outcomes of non-amblyopic eyes were also analyzed as a control group.

PATIENTS AND METHODS

PATIENTS

This retrospective comparative study evaluated amblyopic patients who received laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) at Optical Express surgical centers in the United Kingdom between February 2013 and October 2017. This study was deemed exempt from review by the Committee on Human Research of the University of California, San Francisco, because it involved only de-identified data. This study was compliant with the Health Insurance Portability and Accountability Act of 1996 and adhered to the tenets of the Declaration of Helsinki.

The database of Optical Express (Glasgow, United Kingdom) was searched to identify patients with a history of amblyopia who had undergone LASIK or PRK between February 2013 and October 2017. Patients were included if they had a preoperative corrected distance visual acuity (CDVA) of 20/30 or worse in the amblyopic eye and documentation of being diagnosed as having amblyopia in childhood. Optical Express clinical guidelines do not allow patients with a CDVA of worse than 20/80 in the amblyopic eye to undergo surgery; thus, all amblyopic eyes had a CDVA ranging from 20/30 to 20/80. Additionally, patients had to have a CDVA in the non-amblyopic eye of 20/25 or better to undergo surgery. Patients with less than 1 month of follow-up were excluded. All patients undergoing surgery had to meet the general inclusion criteria for excimer laser surgery, such as normal topography, a calculated postoperative corneal stromal bed thickness of greater than 250 mm (LASIK patients) or greater than 350 mm (PRK patients) in each eye, and age older than 18 years. Exclusion criteria included previous refractive or intraocular surgery, suspected keratoconus, abnormal corneal topography, severe dry eye disease, or other coexisting ocular disease.

All LASIK and PRK procedures were performed by experienced surgeons using standard techniques as described previously.[13] For LASIK procedures, the IntraLase iFS femtosecond laser (Abbott Medical Optics, Inc) with a flap thickness of 100 to 120 mm was used for laser-cut flaps and the Moria M2 mechanical microkeratome (Moria) was used for mechanical flaps, with an estimated flap thickness of 130 mm. For PRK procedures, the epithelium was removed using an alcohol solution. The Visx Star S4 excimer laser (Abbott Medical Optics, Inc) was used for all ablations. For LASIK patients, a third-generation fluoroquinolone and 1% prednisolone acetate were used each four times per day for 1 week, and the patients also were instructed to use an artificial tear solution four times per day for 1 month. The PRK patients received a third- or fourth-generation fluoroquinolone four times per day for 1 week (or until the epithelial defect was healed), as well as fluorometholone 0.1% four times per day for the first week followed by a weekly taper over the course of the next 3 weeks. Patients also received tetracaine 1% eye drops and were instructed to use them sparingly as needed for pain during the first 3 postoperative days and artificial tears four times per day for 1 week.

All patients had a formal informed consent process for their surgical procedure before surgery. As part of their consent process, all patients involved in the study agreed that their de-identified data could be used in statistical analysis and research.

DATA COLLECTION

Patient demographic information (age and gender) was obtained retrospectively from the electronic medical record. The preoperative ophthalmic examination included manifest and cycloplegic refraction, which was performed by experienced optometrists using a resolution-based technique in which the endpoint is the least amount of minus sphere that results in the best visual acuity. Monocular and binocular CDVA using Snellen visual acuity chart, slit-lamp biomicroscopy, dilated fundus evaluation, autorefraction and tonometry (Tonoref II; Nidek Co Ltd), corneal topography (Pentacam; Oculus Optikgeräte GmbH), ultrasound pachymetry (Pachymate; DGH Technology Inc), and wavefront aberration measurement (iDesign; Johnson & Johnson Vision Care, Inc) were performed. Manifest and cycloplegic refraction and CDVA were obtained preoperatively and at 1 and 3 months postoperatively. Uncorrected distance visual acuity (UDVA) was available at the 1- and 3-month postoperative time points.

TABLE 1
Preoperative Patient Characteristics

Variable	Amblyopic Eye	Fellow Eye	*P*
No. of eyes	169	154	
Age (years)			
Mean ± SD	36.2 ± 10.8	35.8 ± 11.0	.77
Range	18 to 58	18 to 58	
Refraction, n (%)			
Myopia	130 (76.9%)	125 (81.2%)	.41
Hyperopia	39 (23.1%)	29 (18.8%)	
Sphere (D)			
Mean ± SD	-1.72 ± 3.61	-1.56 ± 2.87	.66
Range	-9.25 to 4.50	-9.50 to 4.25	
Cylinder (D)			
Mean ± SD	-2.07 ± 1.55	-1.49 ± 1.16	< .01
Range	-6.00 to 0.00	-6.00 to 0.00	
Spherical equivalent (D)			
Mean ± SD	-2.76 ± 3.67	-2.31 ± 2.88	.21
Range	-11.00 to +4.13	-11.00 to +4.13	
CDVA, logMAR (Snellen)			
Mean ± SD	0.24 ± 0.05 (20/40)	-0.03 ± 0.07 (20/20)	< .01
Range	0.20 (20/32) to 0.60 (20/80)	-0.20 (20/12.5) to 0.10 (20/25)	

SD = standard deviation; D = diopters; CDVA = corrected distance visual acuity

Statistical Analysis

Visual acuity was converted into logMAR units for statistical analysis and Snellen equivalent is also provided. The Kolmogorov-Smirnov test was used to determine whether the continuous variables were normally distributed. Continuous variables were described as the mean ± standard deviation, and the categorical variables were described as proportions. The paired *t* test or Wilcoxon ranked-sum test (depending on normality assumption) was used for comparisons between continuous variables of preoperative and postoperative visits. The unpaired *t* test or Mann-Whitney *U* test was used to compare continuous variables of independent groups (amblyopic eyes and fellow eyes) and subgroups (myopic eyes and hyperopic eyes). The chi-square test or Fisher exact test was used to compare proportions. All data were entered into Microsoft Office Excel software (version 16.24; Microsoft Corporation) and analyzed using the SPSS statistics software package (version 25 for Mac; IBM Corporation). A *P* value of less than .05 was considered statistically significant.

RESULTS

A total of 164 patients (323 eyes) met the inclusion criteria. Of these, 94 (57.3%) were male and 70 (42.7%) were female. All patients underwent LASIK (90.1%, 291 eyes) or PRK (9.9%, 32 eyes). The eyes were divided into an amblyopic eyes group (169 eyes) and a fellow eyes group (154 eyes) for analysis. Ten patients did not undergo surgery on their non-amblyopic eye. All patients attended follow-up for at least 1 month or longer. **Table 1** shows the demographic characteristics and preoperative data.

The 3-month follow-up rate was 50.8% (86 of 169). Three months postoperatively, 61 (70.9%) amblyopic eyes and 66 (80.5%) fellow eyes had manifest spherical equivalent within ±0.50 diopters (D) of plano (*P* = .61, Fisher exact test) and 80 (93.0%) amblyopic eyes and 76 (92.7%) fellow eyes had manifest spherical equivalent within ±1.00 D (*P* = .95, Fisher exact test) (**Figures 1-2**). There was no statistically significant difference in manifest spherical equivalent between the two groups preoperatively (*P* = .21, independent *t* test). Similarly, no statistically significant difference was found in the mean manifest spherical equivalent between the two groups at any follow-up visit (*P* = .53, 1 month postoperatively; *P* = .73, 3 months postoperatively, independent *t* test). The reduction of refractive sphere, cylinder, and manifest spherical equivalent

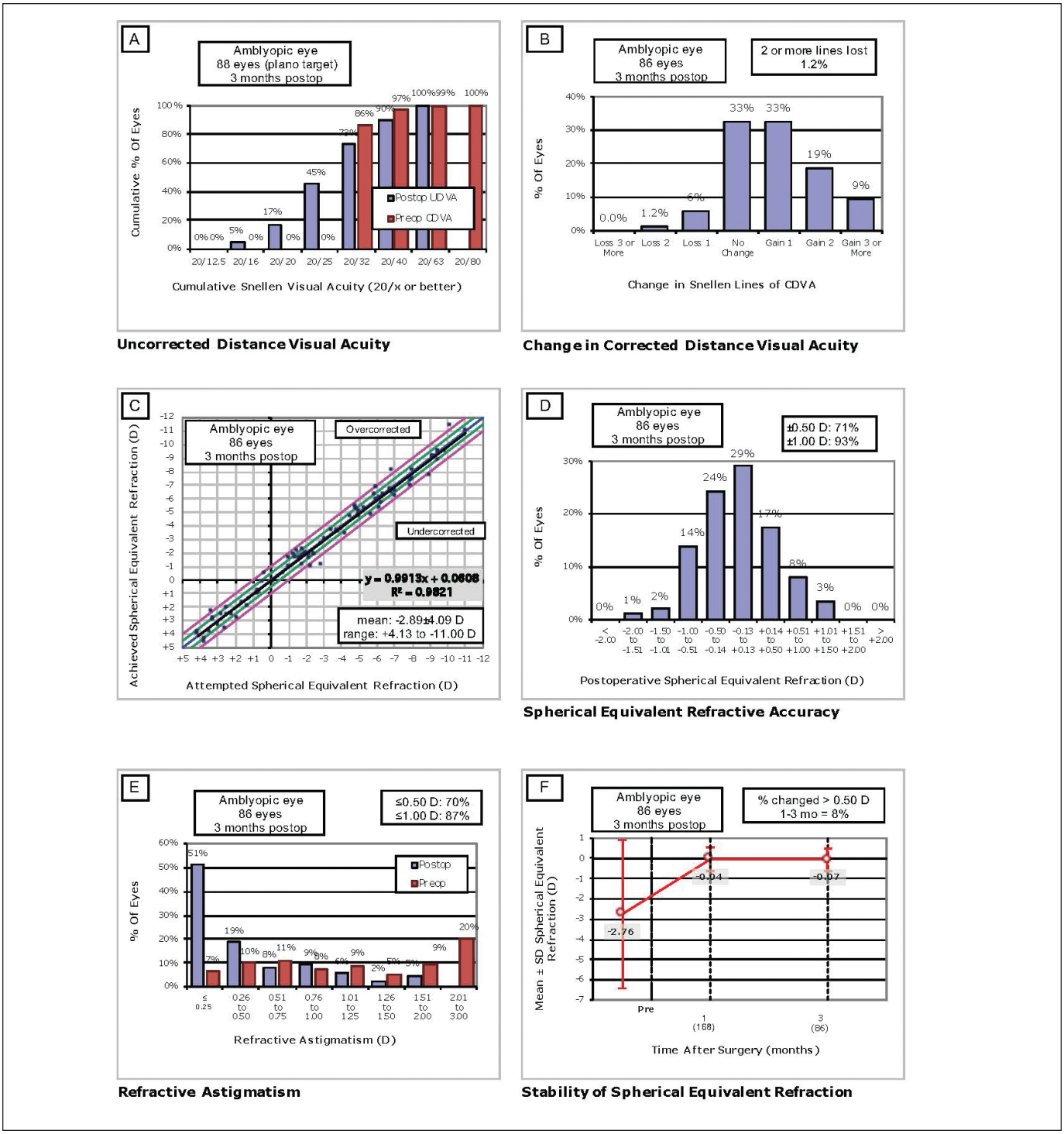

Figure 1. Visual outcomes reported in Standard Graphs of Refractive Surgery for the amblyopic eyes. UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; D = diopters

was statistically significant in both groups (**Table A**, available in the online version of this article).

The percentage of eyes achieving UDVA of 20/20 or better was 16.9% (15 eyes) in amblyopic eyes and 61.9% (52 eyes) in fellow eyes ($P < .01$, Pearson chi-square test). The mean 3-month postoperative UDVA was 0.19 ± 0.16 logMAR (20/32 Snellen) for amblyopic eyes and 0.02 ± 0.15 logMAR (20/25 Snellen) for fellow eyes ($P < .01$, independent t test) (**Figures 1-2**). The mean 3-month postoperative CDVA was 0.13 ±

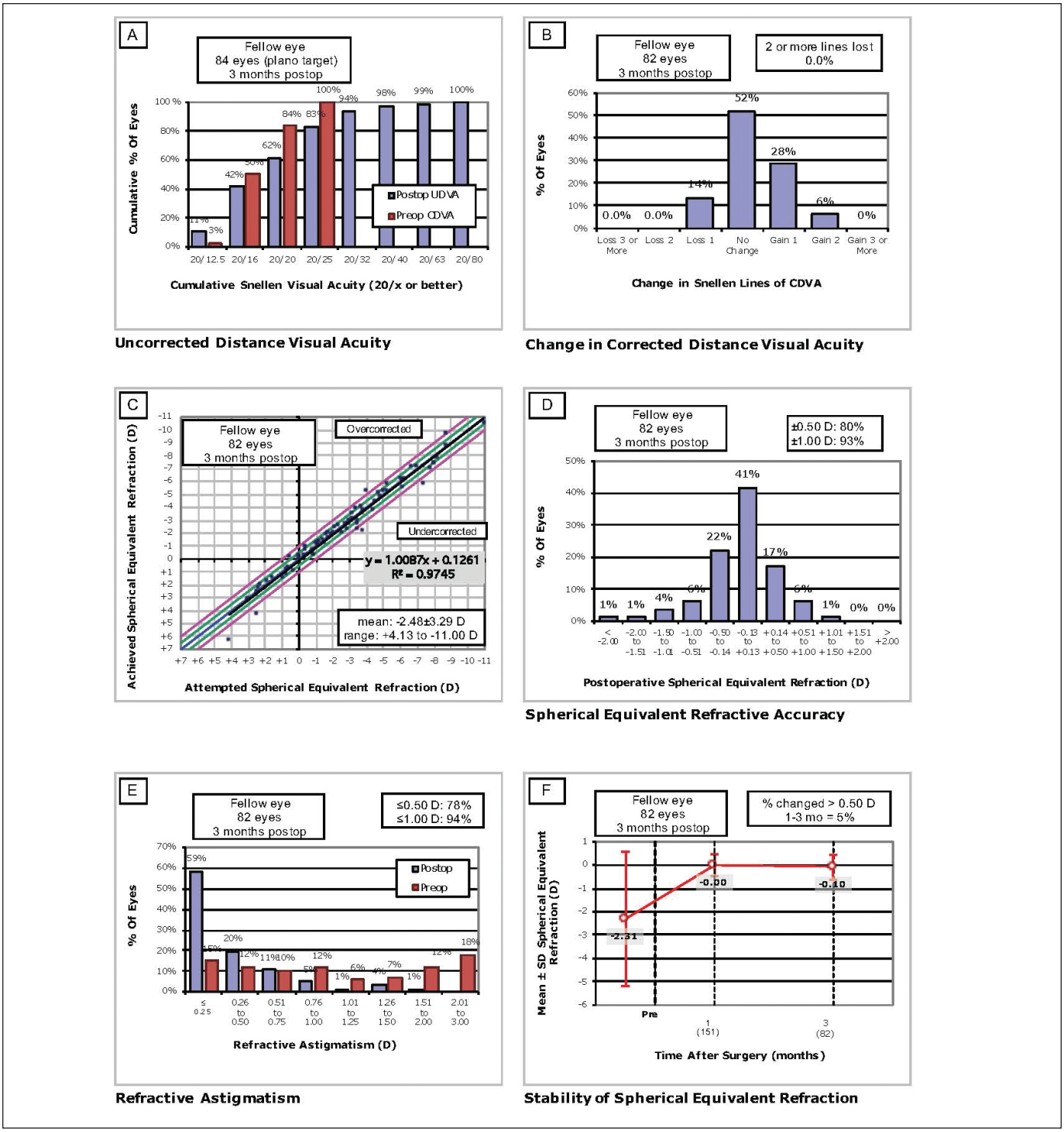

Figure 2. Visual outcomes reported in Standard Graphs of Refractive Surgery for the fellow eyes. UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; D = diopters

0.13 logMAR (20/30 Snellen) for amblyopic eyes and -0.04 ± 0.07 logMAR (20/20 Snellen) for fellow eyes ($P < .01$, independent t test). The mean 3-month postoperative CDVA increased significantly for amblyopic eyes ($P < .01$, paired t test); however, there was no statistically significant increase found for fellow eyes ($P = .11$, paired t test) (**Table A**).

Three months postoperatively, 1 eye (1.2%) in the amblyopic group and no eye in the fellow eye group lost two or more lines of CDVA (**Figures 1-2**). The CDVA of

the eye that lost two lines at 3 months postoperatively returned to the preoperative level at the final visit (6 months postoperatively). Three months postoperatively, 27.9% (24 eyes) of amblyopic eyes gained two or more lines of CDVA, which is significantly higher than 6.2% (5 eyes) of all fellow eyes ($P < .01$, Pearson chi-square test). There were no intraoperative or postoperative complications, and no eyes lost CDVA at the last follow-up visit.

In **Table B** (available in the online version of this article), refractive and visual outcomes are subdivided by the manifest spherical equivalent preoperatively in amblyopic eyes. Improvement in refraction and CDVA was statistically significant in each subcategory. **Figure A** (available in the online version of this article) displays changes in manifest spherical equivalent in the subgroups over time. There was no statistically significant difference in the mean manifest spherical equivalent between the subgroups at any follow-up visit ($P = .87$, 1 month postoperatively; $P = .68$, 3 months postoperatively; independent *t* test).

DISCUSSION

Excimer laser surgery has become a common treatment for correction of a wide range of refractive errors. Many authors have reported the efficacy of refractive surgery for amblyopic eyes in pediatric age groups.[14,15] Although a few retrospective studies have shown improvement in adult amblyopic eyes after refractive surgery, most of these were performed on a small number of patients.[3-6,12,16,17] To our knowledge, there are only three studies[5,12,17] presenting the outcomes in a large number of adult amblyopic patients; however, two of them[5,17] only contain myopia or high myopic astigmatism in amblyopic eyes.

In this study, we retrospectively analyzed the outcomes after laser vision correction in 164 patients with amblyopia, including myopia and hyperopia. We found a significant increase of CDVA in 60.5% of amblyopic eyes at 3 months after refractive surgery. The mean CDVA improved from 0.24 ± 0.05 logMAR (20/40 Snellen) preoperatively to 0.13 ± 0.13 logMAR (20/30 Snellen) postoperatively. In our study, the mean spherical equivalent decreased from -2.76 ± 3.67 D preoperatively to -0.07 ± 0.55 D at 3 months postoperatively. Although the preoperative refractive errors of patients were heterogeneous, the postoperative refractive status was close to emmetropia, indicating that outcomes with modern laser vision correction in amblyopic eyes are similar to outcomes in non-amblyopic eyes.[18] This finding is also in agreement with previously reported results after refractive surgery in adult amblyopic eyes.[3,4,12,19]

Oruçoglu-Orucov et al[3] reported a retrospective review of 30 patients (60 eyes) with unilateral amblyopia who underwent LASIK, with improvement in CDVA compared with preoperative CDVA at 11.3 months postoperatively. Similar findings were reported by Sorkin et al,[12] who noted an improvement of mean CDVA in 327 adult amblyopic eyes from 0.27 ± 0.05 logMAR preoperatively to 0.18 ± 0.10 logMAR at 128 days after PRK or LASIK. Meanwhile, the mean spherical equivalent decreased from -5.50 ± 4.24 D preoperatively to -0.21 ± 0.83 D postoperatively.

Comparing the postoperative visual acuity with other studies is difficult because of variations in the range of preoperative visual acuity and refractive error. However, the percentage of eyes that gained two or more lines in postoperative CDVA is comparable to those in the current study. In our study, 3 months postoperatively, 27.9% (24 eyes) of all amblyopic eyes gained two or more lines of CDVA, which is significantly higher than 6.2% (5 eyes) in all fellow eyes. This finding is in agreement with previously reported results after refractive surgery in adult amblyopic eyes. **Table C** (available in the online version of this article) provides a literature summary of visual outcomes and follow-up time in adults with amblyopia after laser vision correction.

For example, Sorkin et al[12] found 75 eyes (22.9%) gained two Snellen lines and 32 eyes (9.8%) gained three or more Snellen lines. Gonzalez-Lopez et al[5] reported a series of 1,310 eyes that had LASIK with a mean follow-up of 121.8 ± 52.8 days. In that study, 9.62% of eyes gained two Snellen lines and 3.21% of eyes gained three or more Snellen lines. In a study by Cagil et al[4] of 50 patients with anisometropic amblyopia, 22% gained two lines and 26% gained three or more lines. Agca et al[6] found 25% (14 eyes) of 57 amblyopic eyes experienced two or more lines of CDVA improvement at 6 months postoperatively. Arruabarrena et al[17] reported 20% of 35 eyes with a preoperative CDVA of 20/33 or worse had an increase of two or more lines in CDVA at 3 months after LASIK. Roszkowska et al[20] reported a case series of 68 amblyopic eyes that underwent PRK and found 14 eyes (20.6%) gained two lines and 8 eyes (11.8%) gained three lines of CDVA at 1 year postoperatively. Dedhia and Behl[19] performed LASIK on 21 eyes of 21 patients with amblyopia and found CDVA improved by two or more lines in 52.4% of eyes at 3 months postoperatively.

There is large variability in the percentage of eyes that gained lines postoperatively among those studies due to variations in the criteria for the definition of amblyopia. Nevertheless, in all studies, an improvement in CDVA after refractive surgery was observed in a large portion of amblyopic eyes. This might be due to a ceiling effect for amblyopic eyes, in that those eyes with worse baseline CDVA may have more room to

improve and thus treatment in these eyes would have a greater effect. Conversely, fellow eyes with better initial CDVA may have less room for improvement.

Hyperopic laser techniques ablate a paracentral circular area of tissue to steepen the central cornea.[21] Thus, it is not uncommon to clinically observe visual and refractive outcomes of refractive surgery that are less predictable in hyperopic eyes than in myopic eyes,[22,23] and there is a greater tendency toward regression and a heightened risk of losing UDVA with hyperopic eyes.[24,25]

However, when we classified the amblyopic eyes by preoperative hyperopia versus myopia, we found no statistically significant difference in CDVA and the mean manifest spherical equivalent between myopic eyes and hyperopic eyes at any follow-up visit. Similar findings were reported by Cagil et al,[4] who noted there was no significant difference in the increase in CDVA between myopic patients and hyperopic patients after PRK. Nevertheless, our outcome is in contrast to that of Sakatani et al,[16] who found that the CDVA improvement was significant in eyes with myopia but not significant in eyes with hyperopia. The previous study only included 21 eyes: 7 eyes had myopia, 7 eyes had hyperopia, and 3 eyes had mixed astigmatism.

Although our findings indicate that the CDVA of amblyopic eyes improved significantly after laser vision correction, the physiologic mechanisms underlying this improvement are not well understood. The possible mechanisms may be explained by neural plasticity and corneal plane correction. Although it is often stated that visual system plasticity is confined to the childhood period, there is accumulating evidence to show that a significant degree of neural plasticity exists in adults, which may have a positive role in clinically significant improvement in visual acuity.[26,27]

Recent research shows a previously unsuspected high potential of neuronal plasticity in adult animal and human visual systems. For example, some studies[28,29] reported that the plasticity in "mature" animal visual systems was elicited by pharmacological treatment such as valproic acid, fluoxetine, or chondroitinase. In the study by Chino et al,[30] a small retinal lesion was made in one eye of adult cats, and the visual cortex was mapped before and immediately after enucleating the eye with no lesion. They found that substantial reorganization takes place within hours of enucleation. Sale et al[31] showed that environmental enrichment restored visual acuity in adult amblyopic rats.

It is not only animal experimental models studies that give important clues about the presence of visual plasticity in adult eyes; many experimental and clinical studies suggest the adult visual system has the potential for plasticity. Some studies reported perceptual learning has a significant effect on visual function in the adult amblyopic population.[32,33] Likewise, a different study has shown that there was a recovery of visual function in amblyopic eyes when the previously normal fellow eye underwent a significant deterioration in vision.[34] In addition, reports of the recovery of visual acuity in amblyopic eyes after vision loss in the better eye due to macular degeneration suggest the potential for visual improvement in amblyopia later in life.[35]

A second explanation is that the full correction of all refractive errors, including astigmatism, by refractive surgery is undertaken at the corneal plane rather than the spectacle plane, thus eliminating any induced aberrations from spectacle plane correction that might diminish acuity or prevent routine wear of full correction. Although there are multiple different explanations for the improvement in CDVA after laser vision correction, eliminating refractive error appears to be the key to improve visual acuity in adult amblyopia.

The 3-month postoperative refractive accuracy (spherical equivalent within ±0.50 D of the target refraction) in our study seems lower than some other studies. The possible explanation for this may be the loss to follow-up and inclusion of both hyperopic and myopic corrections in our study. Additionally, loss to follow-up at the 3-month visit may have biased our sample toward those with residual refractive error who sought further care.

One of the limitations of this study was that retrospective data were used for analysis. Due to its retrospective nature, multiple examiners examined the patients in this study. The lack of a standardized examination may introduce some bias. Other limitations of this retrospective study are a relatively short follow-up and loss to follow-up. Additionally, because the patients in this study were adults, data on their amblyopic history in childhood were limited.

Despite the limitations, this study demonstrated our experience with laser vision correction for adult amblyopic eyes in a large number of cases. The long-term safety and stability of laser vision correction in adult amblyopic eyes deserves further evaluation. In addition, the change of visual function, which includes not only visual acuity but also contrast sensitivity after laser vision correction in adult amblyopic eyes, will be of great interest in the future. Although our findings have shown visual improvement in adult amblyopia, further investigation is required for a better understanding of the mechanism underlying the observed increase of postoperative CDVA in adult amblyopic patients.

Although it is not possible to predict preoperatively whether CDVA will improve or not, there are still practical advantages of laser vision correction in eyes with

amblyopia. The lifetime risk of bilateral vision impairment for patients with amblyopia is nearly double that for those without amblyopia, whereas the projected lifetime risk of visual loss in the better eye is 1.2%.[36] Therefore, strategies to maximize the visual potential in the amblyopic eye have a direct patient benefit.

The implications of operating on the better-seeing eye in patients with amblyopia are worthy of consideration. As ophthalmologists, our raison d'être is to provide the best possible vision for patients for their entire life. In this study cohort, patients with visual acuity of worse than 20/80 in the worse eye were excluded from having surgery as a means of balancing the benefit for visual improvement with the (extremely rare) risk of catastrophic vision loss in the better-seeing eye. For patients with an acceptable spectacle correction in the better seeing eye who wear only spectacles without impairment, continued spectacles wear may be the least risk-carrying option. However, for patients who wear contact lenses or who have their activities of daily life limited by spectacles wear, the risk of refractive surgery is likely in equipoise. We have good data now on the risk of potential loss of best-corrected visual acuity in laser vision correction,[37] but the risk of vision loss from contact lens wear is still an open question. Data suggest that laser vision correction has an advantage over contact lens wear in terms of patient satisfaction.[38] Providing a full informed consent, including discussing the potential for loss of vision in the better-seeing eye, is critical for patients with amblyopia who are considering undergoing surgery. A potential strategy to mitigate this might be operating on the amblyopic eye first and the better seeing eye second. Ultimately, as physicians, we have the duty to counsel our patients to the best of our ability and to respect our patients' wishes when it comes to surgical decision making.

AUTHOR CONTRIBUTIONS

Study concept and design (XL, SCS, SJH, DT, JMS); analysis and interpretation of data (XL, SCS, SJH, DT, JMS); writing the manuscript (XL, SCS, SJH, DT); critical revision of the manuscript (XL, SCS, SJH, DT, JMS)

REFERENCES

1. Høeg TB, Moldow B, Ellervik C, et al. Danish Rural Eye Study: the association of preschool vision screening with the prevalence of amblyopia. *Acta Ophthalmol*. 2015;93(4):322-329. doi:10.1111/aos.12639
2. Simons K. Amblyopia characterization, treatment, and prophylaxis. *Surv Ophthalmol*. 2005;50(2):123-166. doi:10.1016/j.survophthal.2004.12.005
3. Oruçoglu-Orucov F, Frucht-Pery J, Landau D, Strasman E, Solomon A. LASIK correction of vision in adults with unilateral amblyopia. *J Refract Surg*. 2011;27(1):18-22. doi:10.3928/1081597X-20100325-02
4. Cagil N, Ugurlu N, Cakmak HB, Ilker Kocamis S, Turak D, Simsek S. Photorefractive keratectomy in treatment of refractive amblyopia in the adult population. *J Cataract Refract Surg*. 2011;37(12):2167-2174. doi:10.1016/j.jcrs.2011.06.026
5. Gonzalez-Lopez F, Alonso-Santander N, Mompean B, Bilbao-Calabuig R, Calvache JA, Beltran J. Visual outcomes in adult amblyopic eyes with moderate myopia after corneal laser surgery versus copolymer phakic intraocular lens implant. *J Cataract Refract Surg*. 2015;41(11):2513-2523. doi:10.1016/j.jcrs.2015.05.025
6. Agca A, Ozgürhan EB, Baz O, et al. Laser in situ keratomileusis in adult patients with anisometropic amblyopia. *Int J Ophthalmol*. 2013;6(3):362-369.
7. Scheiman MM, Hertle RW, Beck RW, et al; Pediatric Eye Disease Investigator Group. Randomized trial of treatment of amblyopia in children aged 7 to 17 years. *Arch Ophthalmol*. 2005;123(4):437-447. doi:10.1001/archopht.123.4.437
8. Lanza M, Rosa N, Capasso L, Iaccarino G, Rossi S, Romano A. Can we utilize photorefractive keratectomy to improve visual acuity in adult amblyopic eyes? *Ophthalmology*. 2005;112(10):1684-1691. doi:10.1016/j.ophtha.2005.05.018
9. Alió JL, Ortiz D, Abdelrahman A, de Luca A. Optical analysis of visual improvement after correction of anisometropic amblyopia with a phakic intraocular lens in adult patients. *Ophthalmology*. 2007;114(4):643-647. doi:10.1016/j.ophtha.2006.07.053
10. Kwon SW, Moon HS, Shyn KH. Visual improvement in high myopic amblyopic adult eyes following phakic anterior chamber intraocular lens implantation. *Korean J Ophthalmol*. 2006;20(2):87-92. doi:10.3341/kjo.2006.20.2.87
11. Zhang J, Zhuang J, Yu K-M. Posterior chamber phakic intraocular lens for the correction of high myopic anisometropic amblyopia in adults. *Int J Ophthalmol*. 2018;11(11):1870-1874.
12. Sorkin N, Varssano D, Smadja D, Klein A, Mimouni M, Rosenblatt A. Visual outcomes of laser vision correction in eyes with preoperative amblyopia. *J Cataract Refract Surg*. 2017;43(3):383-388. doi:10.1016/j.jcrs.2016.12.029
13. Schallhorn JM, Schallhorn SC, Ou Y. Factors that influence intraocular pressure changes after myopic and hyperopic LASIK and photorefractive keratectomy: a large population study. *Ophthalmology*. 2015;122(3):471-479. doi:10.1016/j.ophtha.2014.09.033
14. Zhang J, Yu K-M. Femtosecond laser corneal refractive surgery for the correction of high myopic anisometropic amblyopia in juveniles. *Int J Ophthalmol*. 2017;10(11):1678-1685.
15. Ghanem AA, Nematallah EH, El-Adawy IT, Anwar GM. Facilitation of amblyopia management by laser in situ keratomileusis in children with myopic anisometropia. *Curr Eye Res*. 2010;35(4):281-286. doi:10.3109/02713680903556551
16. Sakatani K, Jabbur NS, O'Brien TP. Improvement in best corrected visual acuity in amblyopic adult eyes after laser in situ keratomileusis. *J Cataract Refract Surg*. 2004;30(12):2517-2521. doi:10.1016/j.jcrs.2004.06.026
17. Arruabarrena C, Teus MA, Hernández-Verdejo JL, Cañones R. Visual acuity after laser in situ keratomileusis to correct high astigmatism in adults with meridional amblyopia. *Am J Ophthalmol*. 2011;152(6):964-968.e1. doi:10.1016/j.ajo.2011.05.014
18. Sandoval HP, Donnenfeld ED, Kohnen T, et al. Modern laser in situ keratomileusis outcomes. *J Cataract Refract Surg*. 2016;42(8):1224-1234. doi:10.1016/j.jcrs.2016.07.012
19. Dedhia NC, Behl S. Laser in situ keratomileusis for anisometropic amblyopia. *J Refract Surg*. 2000;16(2 Suppl): S264-S267.
20. Roszkowska AM, Biondi S, Chisari G, Messina A, Ferreri FMB, Meduri A. Visual outcome after excimer laser refractive surgery in adult patients with amblyopia. *Eur J Ophthalmol*.

2006;16(2):214-218. doi:10.1177/112067210601600204

21. Corones F, Gobbi PG, Vigo L, Brancato R. Photorefractive keratectomy for hyperopia: long-term nonlinear and vector analysis of refractive outcome. *Ophthalmology*. 1999;106(10):1976-1982. doi:10.1016/S0161-6420(99)90411-6
22. Zaldivar R, Oscherow S, Bains HS. Five techniques for improving outcomes of hyperopic LASIK. *J Refract Surg*. 2005;21(5 Suppl):S628-S632.
23. Cobo-Soriano R, Llovet F, González-López F, Domingo B, Gómez-Sanz F, Baviera J. Factors that influence outcomes of hyperopic laser in situ keratomileusis. *J Cataract Refract Surg*. 2002;28(9):1530-1538. doi:10.1016/S0886-3350(02)01367-6
24. Gil-Cazorla R, Teus MA, de Benito-Llopis L, Mikropoulos DG. Femtosecond laser vs mechanical microkeratome for hyperopic laser in situ keratomileusis. *Am J Ophthalmol*. 2011;152(1):16-21.e2. doi:10.1016/j.ajo.2011.01.009
25. Kanellopoulos AJ, Conway J, Pe LH. LASIK for hyperopia with the WaveLight excimer laser. *J Refract Surg*. 2006;22(1):43-47. doi:10.3928/1081-597X-20060101-10
26. Vuori E, Tervo TMT, Holopainen MVA, Holopainen JM. Improvement of visual acuity following refractive surgery for myopia and myopic anisometropia. *J Refract Surg*. 2007;23(5):447-455. doi:10.3928/1081-597X-20070501-05
27. Levi DM, Li RW. Improving the performance of the amblyopic visual system. *Philosophical Transactions Royal Soc Lond Ser B Biological Sci*. 2009;364(1515):399-407.
28. Maya Vetencourt JF, Sale A, Viegi A, et al. The antidepressant fluoxetine restores plasticity in the adult visual cortex. *Science*. 2008;320(5874):385-388. doi:10.1126/science.1150516
29. Silingardi D, Scali M, Belluomini G, Pizzorusso T. Epigenetic treatments of adult rats promote recovery from visual acuity deficits induced by long-term monocular deprivation. *Eur J Neurosci*. 2010;31(12):2185-2192. doi:10.1111/j.1460-9568.2010.07261.x
30. Chino YM, Kaas JH, Smith EL III, Langston AL, Cheng H. Rapid reorganization of cortical maps in adult cats following restricted deafferentation in retina. *Vision Res*. 1992;32(5):789-796. doi:10.1016/0042-6989(92)90021-A
31. Sale A, Maya Vetencourt JF, Medini P, et al. Environmental enrichment in adulthood promotes amblyopia recovery through a reduction of intracortical inhibition. *Nat Neurosci*. 2007;10(6):679-681. doi:10.1038/nn1899
32. Polat U, Ma-Naim T, Belkin M, Sagi D. Improving vision in adult amblyopia by perceptual learning. *Proc Natl Acad Sci USA*. 2004;101(17):6692-6697. doi:10.1073/pnas.0401200101
33. Levi DM, Polat U, Hu YS. Improvement in Vernier acuity in adults with amblyopia: practice makes better. *Invest Ophthalmol Vis Sci*. 1997;38(8):1493-1510.
34. Moseley M, Fielder A. Improvement in amblyopic eye function and contralateral eye disease: evidence of residual plasticity. *Lancet*. 2001;357(9260):902-904. doi:10.1016/S0140-6736(00)04231-8
35. El Mallah MK, Chakravarthy U, Hart PM. Amblyopia: is visual loss permanent? *Br J Ophthalmol*. 2000;84(9):952-956. doi:10.1136/bjo.84.9.952
36. van Leeuwen R, Eijkemans MJC, Vingerling JR, Hofman A, de Jong PTVM, Simonsz HJ. Risk of bilateral visual impairment in individuals with amblyopia: the Rotterdam study. *Br J Ophthalmol*. 2007;91(11):1450-1451. doi:10.1136/bjo.2006.113670
37. Schallhorn JM, Schallhorn SC, Teenan D, Hannan SJ, Pelouskova M, Venter JA. Incidence of intraoperative and early postoperative adverse events in a large cohort of consecutive laser vision correction treatments. *Am J Ophthalmol*. 2020;210:97-106. doi:10.1016/j.ajo.2019.10.011
38. Price MO, Price DA, Bucci FA Jr, Durrie DS, Bond WI, Price FW Jr. Three-year longitudinal survey comparing visual satisfaction with LASIK and contact lenses. *Ophthalmology*. 2016;123(8):1659-1666. doi:10.1016/j.ophtha.2016.04.003

TABLE A

Preoperative and Postoperative Outcomes of Amblyopic and Fellow Eyes

	Preoperative		1 Month Postoperative			3 Months Postoperative		
Parameter	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	***P*[a]**	**Mean ± SD**	**Range**	***P*[b]**
Amblyopic eye								
Eyes (n)	169		168			86		
UDVA, logMAR (Snellen)	–	–	0.19 ± 0.15 (20/32)	-0.08 (20/20) to 0.78 (20/125)	N/A	0.19 ± 0.16 (20/32)	-0.08 (20/20) to 0.90 (20/160)	.87
CDVA, logMAR (Snellen)	0.24 ± 0.05 (20/40)	0.20 (20/32) to 0.60 (20/80)	0.13 ± 0.13 (20/30)	-0.10 (20/16) to 0.52 (20/70)	< .01	0.13 ± 0.13 (20/30)	-0.10 (20/16) to 0.52 (20/70)	.56
Sphere (D)	-1.72 ± 3.61	-9.50 to 4.50	0.19 ± 0.61	-2.50 to 2.25	< .01	0.18 ± 0.53	-1.25 to 1.50	.051
Cylinder (D)	-2.07 ± 1.55	-6.00 to 0.00	-0.46 ± 0.46	-2.00 to 0.00	< .01	-0.49 ± 0.52	-2.00 to 0.00	.39
Spherical equivalent	-2.76 ± 3.67	-11.00 to 4.13	-0.04 ± 0.59	-2.88 to 2.00	< .01	-0.07 ± 0.55	-1.75 to 1.30	.15
Fellow eye								
Eyes (n)	154		151			82		
UDVA, logMAR (Snellen)	–	–	-0.00 ± 0.13 (20/20)	-0.18 (20/16) to 0.60 (20/80)	N/A	0.02 ± 0.15 (20/25)	-0.18 (20/16) to 0.60 (20/80)	.10
CDVA, logMAR (Snellen)	-0.03 ± 0.07 (20/20)	-0.20 (20/12.5) to 0.10 (20/25)	-0.03 ± 0.08 (20/20)	-0.18 (20/16) to 0.22 (20/40)	.09	-0.04 ± 0.07 (20/20)	-0.18 (20/16) to 0.10 (20/25)	.02
Sphere (D)	-1.56 ± 2.87	-9.50 to 4.25	0.15 ± 0.46	-1.50 to 1.75	< .01	0.10 ± 0.52	-1.75 to 1.50	.28
Cylinder (D)	-1.49 ± 1.16	-6.00 to 0.00	-0.29 ± 0.36	-2.25 to 0.00	< .01	-0.39 ± 0.42	-2.00 to 0.00	.79
Spherical equivalent	-2.31 ± 2.88	-11.00 to 4.13	0.00 ± 0.48	-2.13 to 1.25	< .01	-0.10 ± 0.54	-2.13 to 1.30	.24

SD = standard deviation; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; D = diopters; N/A = not applicable

[a] *Preoperative to 1 month postoperative.*

[b] *1 month postoperative to 3 months postoperative.*

TABLE B

Refractive and Visual Outcomes Subdivided for Myopic and Hyperopic Eyes

	Preoperative		1 Month Postoperative			3 Months Postoperative		
Parameter	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**	***P*[a]**	**Mean ± SD**	**Range**	***P*[b]**
Myopic eye								
Eyes (n)	129		128			63		
Sphere (D)	-3.18 ± 2.77	-9.50 to 2.00	0.19 ± 0.58	-2.50 to 2.25	< .01	0.15 ± 0.52	-1.25 to 1.50	.05
Cylinder (D)	-2.24 ± 1.57	-6.00 to 0.00	-0.46 ± 0.47	-2.00 to 0.00	< .01	-0.46 ± 0.54	-2.00 to 0.00	.15
Spherical equivalent	-4.30 ± 2.64	-11.00 to -0.13	-0.04 ± 0.57	-2.88 to 2.00	< .01	-0.08 ± 0.56	-1.75 to 1.30	.21
CDVA, logMAR (Snellen)	0.24 ± 0.05 (20/40)	0.22 (20/40) to 0.60 (20/80)	0.13 ± 0.13 (20/30)	-0.08 (20/20) to 0.52 (20/70)	< .01	0.12 ± 0.13 (20/30)	-0.08 (20/20) to 0.52 (20/70)	.86
UDVA, logMAR (Snellen)	–	–	0.19 ± 0.15 (20/32)	-0.08 (20/20) to 0.78 (20/125)	N/A	0.17 ± 0.16 (20/30)	-0.08 (20/20) to 0.90 (20/160)	.62
Hyperopic eye								
Eyes (n)	40		40			23		
Sphere (D)	2.99 ± 1.05	1.00 to 4.50	0.20 ± 0.68	-2.25 to 1.75	< .01	0.26 ± 0.54	-0.75 to 1.25	.65
Cylinder (D)	-1.53 ± 1.40	-6.00 to 0.00	-0.46 ± 0.44	-1.50 to 0.00	< .01	-0.57 ± 0.47	-1.50 to 0.00	.49
Spherical equivalent	2.23 ± 1.26	0.00 to 4.13	-0.02 ± 0.67	-2.63 to 1.63	< .01	-0.02 ± 0.54	-0.88 to,1.13	.49
CDVA, logMAR (Snellen)	0.23 ± 0.05 (20/40)	0.20 (20/32) to 0.52 (20/70)	0.13 ± 0.12 (20/30)	-0.10 (20/16) to 0.40 (20/50)	< .01	0.16 ± 0.12 (20/30)	-0.10 (20/16) to 0.40 (20/40)	.39
UDVA, logMAR (Snellen)	–	–	0.19 ± 0.14 (20/32)	-0.08 (20/20) to 0.52 (20/70)	N/A	0.23 ± 0.14 (20/40)	-0.08 (20/20) to 0.52 (20/70)	.42

SD = standard deviation; CDVA = corrected distance visual acuity; UDVA = uncorrected distance visual acuity; D = diopters; N/A = not applicable

[a]*Preoperative to 1 month postoperative.*

[b]*1 month postoperative to 3 months postoperative.*

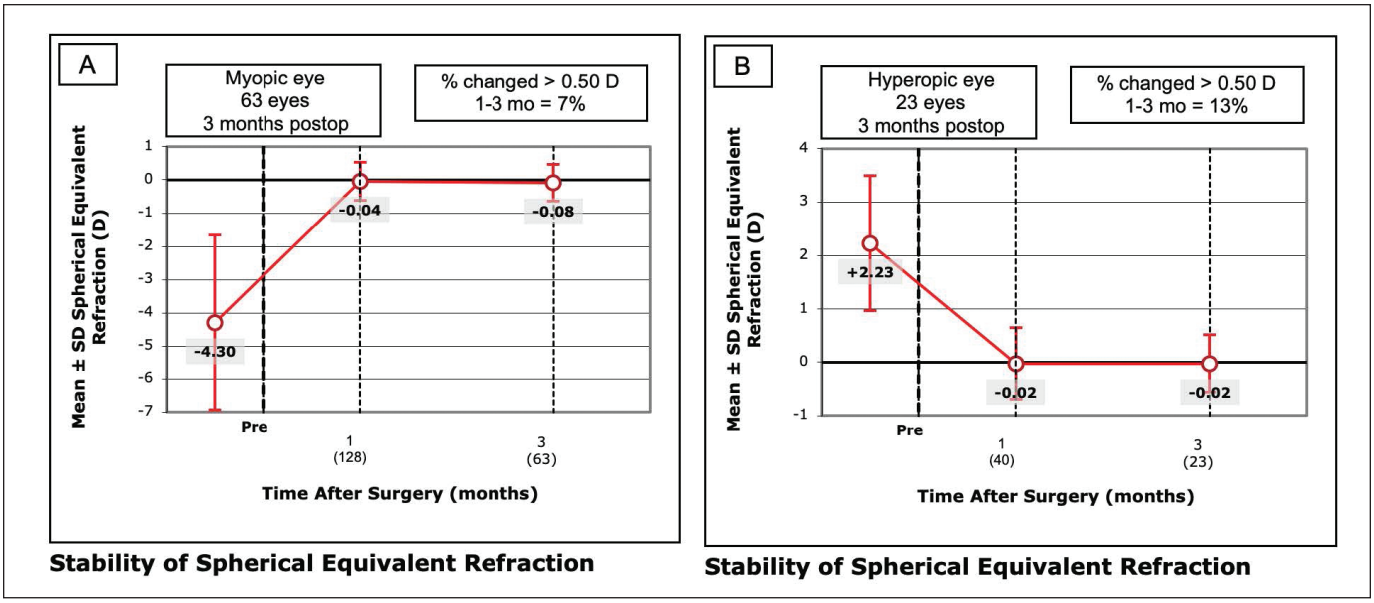

Figure A. Change in manifest spherical equivalent over time for (A) myopic eyes and (B) hyperopic eyes. D = diopters; SD = standard deviation

TABLE C

Summary of Studies Available in English Literature on the Vision Outcomes of Adult Amblyopia After LVC

Study	Eyes (n)	Type of LVC	Myopia/Hyperopia	Follow-up	Preop CDVA, logMAR (Snellen)	Postop CDVA, logMAR (Snellen)	Gain ≥ 2 Lines of CDVA
Sorkin et al (2017)[12]	327	LASIK & PRK	291/34	128 ± 92 days	0.27 ± 0.05 (20/40)	0.18 ± 0.10 (20/30)	32.7%
Gonzalez-Lopez et al (2015)[5]	1,310	LASIK	1,310/0	121.8 ± 52.8 days	0.22 ± 0.09 (20/40)	0.11 ± 0.10 (20/30)	12.83%
Agca et al (2013)[6]	57	LASIK	N/A	6 months	0.23 (20/40)	0.13 (20/30)	25%
Cagil et al (2011)[4]	50	PRK	34/16	6 months	0.47 ± 0.17 (Snellen)	0.61 ± 0.19 (Snellen)	48%
Arruabarrena et al (2011)[17]	205	LASIK	N/A	3 months	0.77 ± 0.18 (Snellen)	0.81 ± 0.19 (Snellen)	20%
Oruçoglu-Orucov et al (2011)[3]	30	LASIK	N/A	11.3 ± 12.1 months	0.50 ± 0.13 (decimal)	0.57 ± 0.20 (decimal)	16.7%
Roszkowska et al (2006)[20]	68	PRK	68/0	12 months	N/A	N/A	32.4%
Sakatani et al (2004)[16]	21	LASIK	13/8	226 days	0.24 (20/40)	0.16 (20/30)	N/A

LVC = laser vision correction; CDVA = corrected distance visual acuity; LASIK = laser in situ keratomileusis; PRK = photorefractive keratectomy