Involvement of Neural Adaptation in the Recovery of Vision After Laser Refractive Surgery

Konrad Pesudovs, PhD

ABSTRACT

PURPOSE: To investigate whether the gradual improvement in unaided visual acuity commonly seen after laser refractive surgery is attributable, in part, to neural adaptation to blur.

METHODS: Unaided logMAR visual acuity was measured at presentation (blur adapted) and immediately after refraction and removal of refractive correction (correction adapted) in 26 patients with low myopic residual refractive error after laser in situ keratomileusis (LASIK). The difference in unaided visual acuity (correction adapted − blur adapted) indicates a dominance of practice effect (if negative) or blur adaptation (if positive). A combination of blur adaptation and practice effect is possible.

RESULTS: Overall, the mean unaided visual acuity at presentation (blur adapted) was 0.16±0.16 (mean±standard deviation) logMAR, and the mean unaided visual acuity immediately after refraction and removal of refractive correction (correction adapted) was 0.14±0.14 logMAR, giving a difference (correction adapted − blur adapted) of −0.02±0.06 logMAR. This difference was not significant (analysis of variance [ANOVA] $F_{1,25}$=0.204, P>.05), suggesting neither blur adaptation nor practice effect. However, during the first 10 weeks after surgery, the difference in unaided visual acuity was −0.07±0.05 logMAR, suggesting a practice effect. After 10 weeks, the mean difference was +0.02±0.05 logMAR, suggesting any practice effect is offset by blur adaptation. These values were significantly different (ANOVA $F_{1,25}$=13.53, P<.01).

CONCLUSIONS: These data suggest that patients do not adapt to surgically induced blur, on average, until 10 weeks after LASIK. The reason for this delay is uncertain; perhaps instability of blur hinders adaptation during the early postoperative period. Part of the gradual visual improvement after LASIK appears to be due to neural adaptation to blur. [*J Refract Surg*. 2005;21:144-147.]

Blur adaptation is characterized by vision being measurably better after a prolonged period of blur, compared to immediately after initiating blur. This occurs in naturally existing myopia,[1] and in lens-induced blur.[2,3] Adaptation to blur has also been demonstrated for blurred photographic images[4] and using an adaptive optics system to manipulate blur caused by wavefront aberration.[5,6] However, regardless of the methodology, neural adaptation to blur is likely a manifestation of spatial frequency adaptation.[7,8]

A normal distribution of refractive outcome from laser refractive surgery occurs with approximately 10.5% requiring retreatment for such off-target results,[9] and between 10% and 77% having 0.50 diopters (D) postoperative refractive error (depending on the level of treated myopia).[10] Uncorrected visual acuity after laser refractive surgery improves with time following surgery.[10,11] This is likely to be due to healing effects including reduced edema, remodeling of corneal epithelium to smooth optics, improved tear film, and disappearance of cellular infiltrate and debris, which act as light-scattering particles. Part of this improvement may also be due to the development of adaptation to blur caused by low levels of postoperative refractive error or induced higher order aberrations.

To investigate this possibility, the blur adaptation response was measured in a series of post-refractive surgery cases with uncorrected low residual myopic refractive error and a postoperative range of times. This was done by measuring unaided visual acuity at presentation (when the habitually uncorrected patient should be adapted to existing blur), refracting the patient and allowing for adaptation to clear vision, and then remeasuring unaided visual acuity immediately after

From the Department of Ophthalmology, Flinders University and Flinders Medical Centre, Bedford Park, Australia.

The author has no proprietary interest in the materials presented herein.

This study was supported by Ultralase, Leeds, United Kingdom. Dr Pesudovs is supported by NHMRC Sir Neil Hamilton Fairley Fellowship 0061, Canberra, Australia.

Correspondence: Konrad Pesudovs, PhD, Dept of Ophthalmology, Flinders University and Flinders Medical Centre, Bedford Park, SA 5042, Australia. Tel: 61 8 8204 4899; Fax: 61 8 8277 0899; E-mail: Konrad.Pesudovs@flinders.edu.au

Received: March 19, 2004

Accepted: August 30, 2004

removal of the refractive correction (adapted to correction). Blur adaptation was calculated according to the existing definition[1,2]: unaided visual acuity adapted to correction − unaided visual acuity adapted to blur. Previous studies suggest that patients with low levels of myopic refractive error should exhibit blur adaptation.[1] This was tested at a range of times after surgery to determine whether blur adaptation was present at all times after surgery or if onset was delayed and therefore may account for part of the gradual improvement in visual acuity after refractive surgery.

MATERIALS AND METHODS

Patient Population

Twenty-six patients were prospectively recruited over a 3-month period in 2002 from a consecutive series presenting for postoperative follow-up after laser in situ keratomileusis (LASIK) at Ultralase, Leeds, United Kingdom. Mean patient age was 41.1±10.5 years (range: 24 to 62 years). Mean time since surgery was 27.7±17.8 weeks (range: 1 to 62 weeks). Mean preoperative refractive error (spherical equivalent refraction) was −1.54±3.23 diopters (D) (range: −6.13 to +4.50 D) and postoperative refractive error was −0.82±0.50 D (range: −0.25 to −2.13 D).

Inclusion criteria were previous LASIK, with at least 0.25 D of residual myopic refractive error, and a corrected visual acuity of ⩾0.10 logMAR. Exclusion criteria were postoperative complications (eg, infection, diffuse lamellar keratitis, etc), ocular pathology or abnormality including amblyopia and strabismus, previous ocular surgery (other than LASIK), neurological problems, systemic disease, or medication use that may affect vision. Each patient was measured once, at one time-point only.

Methods

Visual acuity was measured on a computer-based system positioned at 4 m from the eye. The screen was watched throughout testing as a basic control of accommodation. Visual acuity testing used logMAR principles with five letters presented in each row with rows progressing in size by 0.1 logMAR as per ETDRS chart design.[12] A single row with five randomly selected letters was presented at any one time. There was no repetition of rows, therefore no learning effect related to letter memory. Threshold was controlled using a strict forced-choice protocol with termination of testing after five errors.[13] Scores were calculated using single-letter scoring.

The method for demonstrating blur adaptation involved measuring unaided visual acuity under two conditions, similar to previously published methodology.[1] First, patients' unaided vision was measured at presentation while they were adapted to their habitual unaided vision. According to the entry criteria, this unaided vision was blurred by at least 0.25 D of myopia, therefore this state is referred to as blur adapted. The patient was then refracted, aided visual acuity measured, and the patient was allowed 1 minute for adaptation to corrected vision. Then the correction was removed and unaided visual acuity was immediately remeasured. This is referred to as correction adapted unaided visual acuity. Although a 1-minute period of clear vision may seem a very short period to cause disruption of blur adaptation, the disruption need only last for as long as it takes to measure unaided visual acuity again. There is no suggestion that 1 minute of clear vision would cause a long-standing disruption to blur adaptation. No previous study has addressed the time required to establish adaptation to corrected vision, and it is possible that a longer period of adaptation would result in a larger effect. Nevertheless, this was the paradigm chosen.

The interpretation of the results of this experiment center on the difference between the two unaided visual acuity measurements: unaided visual acuity adapted to correction − unaided visual acuity adapted to blur. This difference is defined as the degree of blur adaptation, with an increasing positive value indicating increasing blur adaptation.[1,2] A previous study found unaided visual acuity adapted to correction to be on average 0.02 logMAR worse than blur adapted unaided visual acuity among low myopes.[1] In this study, a positive difference is interpreted as patients exhibiting adaptation to their postoperative level of blur. A negative difference is also possible. In this study design, blur adapted unaided visual acuity was measured before correction adapted unaided visual acuity. As with any test, a task-practice effect should result in slightly improved performance at repeat measurement. This is independent of any letter memory effect, which was eliminated through randomized letter presentation. If no blur adaptation existed, the difference between the two unaided visual acuity measurements would be dominated by a task practice effect whereby the second measurement would be better than the first (correction adapted unaided visual acuity < blur adapted unaided visual acuity). This would result in a negative difference. Importantly, this task practice effect acts to oppose, not enhance, the measurement of blur adaptation. Therefore, the results may have to be interpreted as a combination of both task practice effect and blur adaptation. Although this may hamper the measurement of the absolute magnitude of blur adaptation, it does not prevent exploration of delay of the onset of blur adaptation as there is no reason why the task practice effect would be different for different periods postoperatively in this cross-sectional study design.

Manifest refraction was determined using subjective refraction only. Subjective refraction was performed using a trial frame at a vertex distance of 12 mm. Careful subjective refraction was undertaken by determination of best vision sphere and the Jackson's cross-cylinder technique. Changes in cylinder power were compensated for by adjustment of sphere power, but all such compensations were double checked subjectively. Each eye was refracted monocularly followed by binocular balancing. The final spherical power was defined as the highest plus value or the lowest minus value that gave the best visual acuity.

Statistics

Differences between unaided visual acuity adapted to blur and adapted to correction were tested using repeated measures analysis of variance (ANOVA). Matching of groups for age and refractive error was also done using ANOVA. All statistical testing was done using SPSS version 10.1 (SPSS Inc, Chicago, Ill).

RESULTS

On presentation, postoperative unaided visual acuity (blur adapted) was +0.16±0.15 logMAR (range: −0.14 to +0.36 logMAR), after refraction aided visual acuity was −0.03±0.07 logMAR (range: −0.18 to +0.10 logMAR), and on retesting immediately after removing refractive correction unaided visual acuity (correction adapted) was +0.14±0.14 logMAR (range: −0.06 to +0.36 logMAR). Therefore, the difference between unaided visual acuity adapted to refractive correction and unaided visual acuity adapted to blur was −0.02±0.06 logMAR (range: −0.14 to 0.14 logMAR) (correction adapted − blur adapted). This was not significantly different (ANOVA $F_{1,25}$=0.204, P>.05), suggesting neither blur adaptation nor practice effect. However, the tendency for blur adaptation varies with time since surgery.

For patients measured during the first 10 weeks after surgery (n=7), the mean difference in unaided visual acuity (correction adapted − blur adapted) was −0.07±0.05 logMAR (range: −0.14 to 0.00 logMAR). Therefore, unaided visual acuity improved at the second measurement, suggesting a significant task practice effect. For patients measured after 10 weeks post-surgery (n=19), the mean difference in unaided visual acuity was +0.02±0.05 logMAR (range: −0.08 to +0.14 logMAR). This suggests blur adaptation (Fig). The mean difference in unaided visual acuity (correction adapted − blur adapted) before 10 weeks post-surgery compared to after 10 weeks post-surgery was significantly different (ANOVA $F_{1,25}$=13.53, P<.01). This difference could not be accounted for by a difference in age: before 10 weeks 40.9±12.7 years, after 10 weeks 41.3±9.9 years ($F_{1,24}$=0.007, P=.93). Nor could the difference be accounted for by a difference in refractive error: postoperative spherical equivalent refraction before 10 weeks −0.83±0.55, after 10 weeks −0.77±0.50 ($F_{1,24}$=0.072, P=.79); postoperative astigmatism before 10 weeks −0.53±0.43, after 10 weeks −0.69±0.48 ($F_{1,24}$=0.640, P=.43).

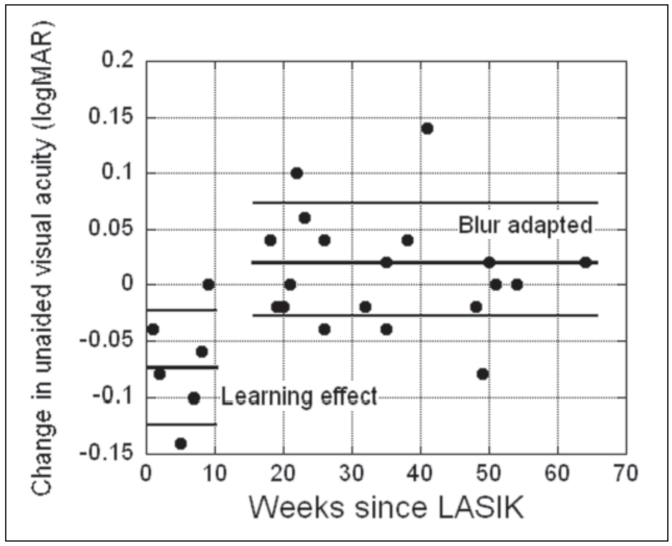

Figure. Blur adaptation represented by the difference in unaided visual acuity (adapted to refractive correction − adapted to blur) as a function of weeks since surgery. In the first 10 weeks (n=7), the mean difference is −0.07±0.05 logMAR, suggesting no blur adaptation but a practice effect where vision is better on the second testing. After 10 weeks (n=19), the mean difference is +0.02±0.05 logMAR, demonstrating the practice effect is offset by blur adaptation. The means of these two groups were significantly different (ANOVA $F_{1,25}$=13.53, P<.01).

DISCUSSION

After 10 weeks following LASIK, a blur adaptation of 0.02 logMAR is measurable when comparing habitual unaided visual acuity to unaided visual acuity measured immediately after allowing time to adjust to clear vision. In this study, the removal of blur by refractive error correction temporarily breaks down blur adaptation. Immediate remeasurement of unaided visual acuity after removal of the correction allows sampling of vision before the re-establishment of blur adaptation. This level of blur adaptation is identical to that reported in naturally occurring low myopia.[1] Adaptation to larger amounts of blur, or using longer periods of clear vision, may result in a larger effect as has been shown with adaptation to spectacle lens induced blur.[2,3] However, blur adaptation is not evident before 10 weeks postoperatively (see Fig). Instead, measurement of unaided visual acuity immediately after removing refractive correction demonstrates an improvement of 0.07 logMAR over presenting unaided visual acuity. This is not consistent with the patients seen after 10 weeks, nor with previously published data in low myopes, and suggests that patients do not appear to be adapted to their existing blur during the first 10 weeks after refractive surgery. Alternatively, this may represent a practice effect. Repeated measurement of visual acuity, without change in conditions, should yield an improved score due to practice effects.[14] Measurement adapted to blur and adapted to correction should represent changed conditions; however, if blur adaptation is not present, conditions will be unchanged. It should be noted that some degree of practice effect probably exists within all of the data but is offset by blur adaptation after 10 weeks postoperatively. Importantly, as this was a cross-sectional dataset, there was no long-term practice effect that may explain the results. Patients were not routinely tested on this monitor-based visual acuity testing equipment as part of their normal postoperative care.

These data suggest it takes approximately 10 weeks for the visual system to adapt to a new state of blur following refractive surgery. Studies of the time course of neural adaptation show a much shorter period.[15] This raises the possibility that there may be two phases of adaptation—a rapid phase, as demonstrated in studies where the visual system is challenged with lens-induced blur,[2] and a slower phase, perhaps involving the embedding of an adaptation response to a constant level of blur. An alternative reason for the delay of adaptation to blur may be instability of blur either due to changing refractive error, aberrations, or other healing processes that cause variation of optical performance (eg, edema, tear film break-up, etc). Adaptation to blur would be hindered by blur not being constant; perhaps by 10 weeks on average, a stable level of blur is attained so that adaptation can occur. If instability of blur due to multiple factors is the delay mechanism this would vary from person to person, which may also explain some of the individual variation in degree and timing of adaptation seen within the cohort.

It is common clinical practice to wait approximately 3 months after LASIK before comprehensively assessing the surgical outcome (generally the larger the correction, the longer the wait, ie, up to 6 months for large corrections). If our approximate 10-week threshold is accurate, patients adapt to their new vision during this time so clinicians can more accurately assess subjective satisfaction, or quality of life outcomes by using clinical questionnaires (eg, QIRC[16]) and make judgments about whether retreatment should be done, based on objective clinical findings correlated with the patient's subjective visual experience and desires after this time. Our findings support in general a minimum 3-month wait before assessing overall results after LASIK.

Although this is a small study, it is large enough to demonstrate a variation in blur adaptation with time following surgery. Although a larger cohort would be desirable, detection and measurement of blur adaptation is easiest with >0.25 D blur. However, laser refractive surgery targeted for an emmetropic outcome does not often result in significant residual myopic refractive error. Furthermore, a prospective study with deliberate induction of residual myopic error to study neural adaptation would be inappropriate. Perhaps this phenomenon could be studied in a setting where monovision correction is commonly performed and therefore significant residual myopic errors are commonplace.

REFERENCES

1. Pesudovs K, Brennan NA. Decreased uncorrected vision after a period of distance fixation with spectacle wear. *Optom Vis Sci*. 1993;70:528-531.
2. Mon-Williams M, Tresilian JR, Strang NC, Kochhar P, Wann JP. Improving vision: neural compensation for optical defocus. *Proc R Soc Lond B Biol Sci*. 1998;265:71-77.
3. George S, Rosenfield M. Blur adaptation and myopia. *Optom Vis Sci*. 2004;81:543-547.
4. Webster MA, Georgeson MA, Webster SM. Neural adjustments to image blur. *Nat Neurosci*. 2002;5:839-840.
5. Artal P, Chen L, Fernandez EJ, Singer B, Manzanera S, Williams DR. Adaptive optics for vision: the eye's adaptation to point spread function. *J Refract Surg*. 2003;19:S585-S587.
6. Artal P, Chen L, Fernandez EJ, Singer B, Manzanera S, Williams DR. Neural compensation for the eye's optical aberrations. *Journal of Vision*. 2004;4:281-287.
7. De Valois KK. Spatial frequency adaptation can enhance contrast sensitivity. *Vision Res*. 1977;17:1057-1065.
8. Georgeson MA, Sullivan GD. Contrast constancy: deblurring in human vision by spatial frequency channels. *J Physiol*. 1975;252:627-656.
9. Hersh PS, Fry KL, Bishop DS. Incidence and associations of retreatment after LASIK. *Ophthalmology*. 2003;110:748-754.
10. Sugar A, Rapuano CJ, Culbertson WW, Huang D, Varley GA, Agapitos PJ, de Luise VP, Koch DD. Laser in situ keratomileusis for myopia and astigmatism: safety and efficacy: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2002;109:175-187.
11. Dausch D, Dausch S, Schroder E. Wavefront-supported photorefractive keratectomy: 12-month follow-up. *J Refract Surg*. 2003;19:405-411.
12. Ferris FL III, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. *Am J Ophthalmol*. 1982;94:91-96.
13. Carkeet A. Modeling logMAR visual acuity scores: effects of termination rules and alternative forced-choice options. *Optom Vis Sci*. 2001;78:529-538.
14. Fiorentini A, Berardi N. Perceptual learning specific for orientation and spatial frequency. *Nature*. 1980;287:43-44.
15. Greenlee MW, Georgeson MA, Magnussen S, Harris JP. The time course of adaptation to spatial contrast. *Vision Res*. 1991;31:223-236.
16. Pesudovs K, Garamendi E, Elliott DB. The Quality of Life Impact of Refractive Correction (QIRC) Questionnaire: development and validation. *Optom Vis Sci*. 2004;81:769-777.